ELEMENTS

OF

MINERALOGY, CRYSTALLOGRAPHY

AND

BLOWPIPE ANALYSIS

FROM A PRACTICAL STANDPOINT

INCLUDING

A DESCRIPTION OF ALL COMMON OR USEFUL MINERALS, THE TESTS NECESSARY FOR THEIR IDENTIFICATION, THE RECOGNITION AND MEASUREMENT OF THEIR CRYSTALS, AND A CONCISE STATEMENT OF THEIR USES IN THE ARTS

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THIRD ENLARGED EDITION

PART I REWRITTEN. PARTS II, III AND IV EXTENSIVELY REVISED
WITH 583 FIGURES AND 448 PAGES OF TEXT

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PREFACE.

In this edition of our text-book we have adhered to the design of the editions of 1895 and 1900, to present the facts leading to a useful knowledge of mineralogy in such a manner that the student in the technical school and the professional man in the field may readily learn to recognize or, when necessary, to determine all important minerals.

We have made a number of changes and additions which experience has shown to be desirable. Some of these are:

Part I., Crystallography, has been entirely rewritten and the attempt has been made to subordinate the study of models to the study of actual crystals.

The introductory portion of Part III., Descriptive Mineralogy, has been carefully revised and rewritten, a chapter added upon "Occurrence and Origin of Minerals"; the discussion of chemical composition and chemical relations of minerals made more thorough; the optical portion simplified and the phenomena of radioactivity, fluorescence and phosphorescence described.

In the descriptions of species the statistics and methods of production have been brought down to date, the lithium minerals assembled, and the carbon minerals elaborated. A few economic species have been added, a few rare species omitted and the descriptions of species of minor importance condensed.

A number of half-tones have been added and in the crystallographic discussions the supplement angles have been used.

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PART III. — DESCRIPTIVE MINERALOGY — *Continued.*

PART I.

CRYSTALLOGRAPHY.

CHAPTER I.

INTRODUCTORY.

Solidification of Chemical Substances.

When a homogeneous substance, for which a chemical formula can be written, passes from the liquid or gaseous state or separates from solution there usually form distinct individual solids which are bounded by plane faces, and possess a certain constancy in shape, which is characteristic of the substance.

Crystals and Crystallization.

These solids are called "crystals" and their formation is called crystallization. It may therefore be said that:

(*a*) CRYSTALS * are solids formed only when a chemical element or a chemical compound solidifies. They are bounded by plane faces at definite angles to each other which are characteristic of the substance.

(*b*) CRYSTALLIZATION is the solidification of a chemical element or compound and must result either in distinct crystals or in *crystal aggregates*, that is, masses of crystals which have been hindered in development by lack of space, or time or other cause.

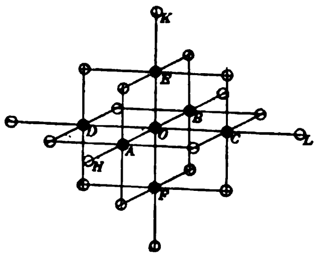
Crystal Structure.

Disregarding the question of the nature of the smallest solid particles of matter, about which little is known, the geometric forms of the crystals and many of their physical characters prove a homogeneous structure, that is, each particle is in a similar position

* The term crystal or rock crystal has been used for over two thousand years as a name for the substance silica when found in colorless angular forms. Certain clear varieties of glass are also known as crystal.

with respect to those surrounding it; each is the center of a precisely similar group, and along any line, and all parallel lines, the particles are equally far apart.

FIG. 1.



Such a structure is illustrated in Fig. 1, the particle O is surrounded by six similar particles A, B, C, D, E and F at fixed distances $OA = OB$, $OC = OD$ and $OE = OF$. Each of the six is itself the center of a similar group, the intervals in the same direction being as before, that is $AH = OA$, $CL = OC$, $EK = OE$ and so on. Different substances differ in the grouping of their particles so that each has its own characteristic crystals. All this has been theoretically considered and the possible variation of regular grouping discussed.*

Regular Structure in Absence of Distinct Crystals.

In the solidification of chemical compounds a regular arrangement of the particles takes place whether distinct crystals are formed or not. This can be proved in many ways; for instance,

(*a*) The masses will often break in directions parallel to planes yielding solids absolutely constant in angles, and these solids can be broken from any part of the mass and of any size.

(*b*) The velocity of transmission† of light, is the same along all *parallel* lines, but is not generally the same along lines not parallel.

(*c*) The same constancy for parallel lines and variation for lines not parallel is shown for other physical characters such as expansion from heat, conductivity of heat or electricity, and even color and luster.

Summation of Preceding Paragraphs.

The important points thus far stated are:

1. That the solidification of chemical substances is a regular

* See Report of Committee "On Structure of Crystals," *Proc. Roy. Soc.*, Section C, Glasgow, 1901, for a general review.

† In glass or other homogeneous solids which are not definite chemical compounds the velocity of transmission is, generally speaking, the same in *all* directions, or if unlike it is without any regularity of difference.

arrangement of the minutest solid particles in straight lines and planes so that each particle is the center of a precisely similar group of particles.

2. That the solidification often results in the formation of polyedral solids called crystals.

3. That different chemical substances have different structures, and the resultant crystals are not alike in shape.

4. That the shapes of the crystals characterize the substance.

The Angles of Crystals.

In any polyedron three sorts of angles exist.

1. Plane angles between the intersections of faces. These are little used.

2. Interfacial or diedral angles. These are the most important.

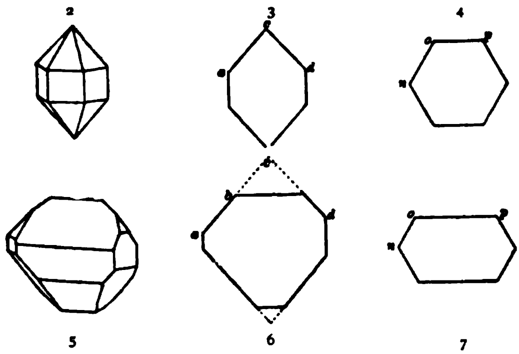
3. Corners or polyedral angles between three or more planes.

Law of Constancy of Interfacial Angles.

The angles of crystals of any one substance conform to the following law: *In all crystals of the same substance the angles between corresponding faces are constant.**

Figs. 2 and 5 represent actual crystals of quartz. Figs. 3 and

FIGS. 2-7.



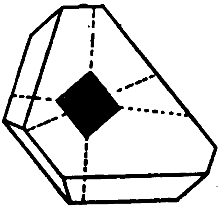
6 are sections of these in the direction of the plane of the paper which show that the angles between corresponding faces are

* Steno in 1669 announced that in rock crystal there was no variation of angle in spite of the variation in relative size of the faces.

Romé Delisle in 1783 measured and described over four hundred crystal forms and announced that in each species "the respective inclination of the faces to each other never varies."

equal. The same is shown by sections at right angles to the paper, Figs. 4 and 7.

FIG. 8.

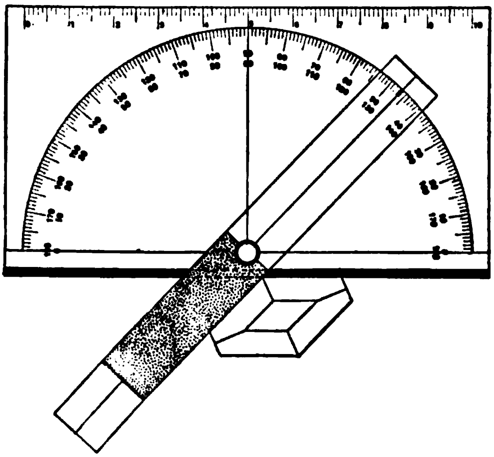


Similarly in Fig. 8 the faces of the magnetite crystal are exactly parallel to those of the octahedron represented within it, that is, such crystals of magnetite are bounded by faces which may or may not be equal in size but in which the angle between adjacent faces is 109° 28′ 16″.

THE APPROXIMATE MEASUREMENT OF INTERFACIAL ANGLES.

Measurements within one or two degrees may be made with *Contact goniometers*, the most simple type of which consist of an arm pivoted upon a protractor. Fig. 9 shows such an instrument

FIG. 9.



consisting of a cardboard on which is printed a semicircle graduated from 0° to 180° in both directions.

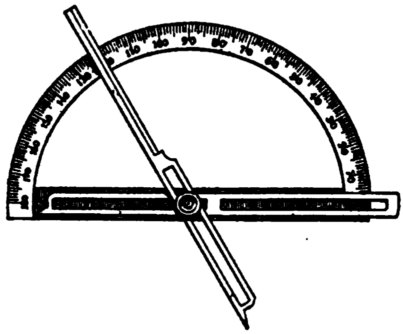
An arm of transparent celluloid is swivelled by means of an eyelet exactly in the center of the semicircle tightly enough to turn with some difficulty.

In measuring, the crystal or model is placed as shown so that the card edge and swinging arm are each perpendicular to the edge of intersection of the two faces, and in such close contact that no light passes between the arms and the faces.

Either the actual angle or its supplement may be read upon the scale.*

A more expensive instrument, Fig. 10, consists of a brass protractor with detachable arms which can be slid upon the pivot until of the most convenient length for the particular crystal.

FIG. 10.



In measuring it is convenient to set the arms at an angle a little less than the angle to be measured, clamp loosely and make the fine adjustment by placing one of the arms in perfect contact with one crystal face, the other arm nearly touching the second face and, while holding between the eye and the light, to bring the second arm into perfect parallelism with the second face by a gentle pressure with the forefinger.

The arms are then replaced on the arc, as in the figure, and the angle is read. In the figure the angle is 120°.

Three measurements should be made and the average should be correct within one degree. After each reading the arm should be unclamped and the new measurement made as if it were a different angle.

The Two-Circle Contact Goniometer.

A convenient instrument † for finding both the symmetry and the crystal angles is shown in Fig. 11. The crystal is fastened with wax to the carrier *t* which permits some adjustment. The rod *R* passes radially through the movable arc *A* and can be pushed in and out or turned. The knife edge *k* is at right angles to *R* and therefore when *R* is turned the edge *k* is always a line of a plane perpendicular to a radius.

To adjust the crystal with any zone ‡ vertical the arc *A* is moved

* This instrument called the Penfield Goniometer, Model B, can be purchased from dealers at 50 cents.

† Goldschmidt's Zweikreisiges Anlege-Goniometer made by Peter Stöe of Heidelberg at 32 marks.

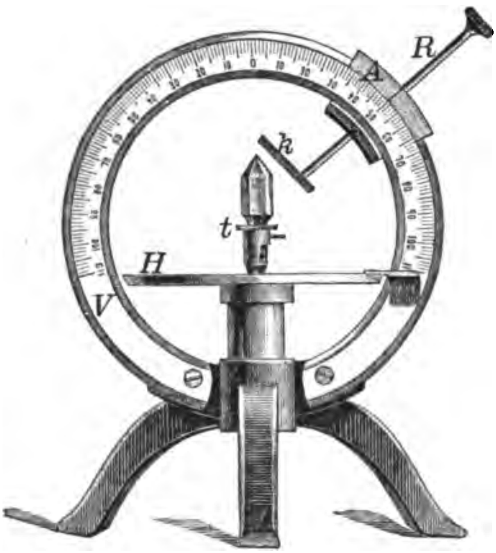
‡ A zone is a series of planes parallel to the same line; intersections of these planes are parallel to this line and to each other. In the case of quartz after adjustment a vertical and oblique face would probably be read alternately as this could be done more quickly.

to 90° on the vertical circle V and the faces of the zone are successively brought by rotation of the horizontal circle to coincide with the revolved knife edge k, that is they are made perpendicular to a horizontal radius and therefore vertical.

The measurement thereafter proceeds as follows:

The horizontal circle H is revolved until each of the faces of the

FIG 11.



vertical zone has been made to coincide with the horizontally placed knife edge k. The successive readings are noted on the horizontal circle.

The arc A is then slid along the vertical circle V and the horizontal circle H is turned until positions are found for which the knife edge during a revolution coincides with an *oblique* face.

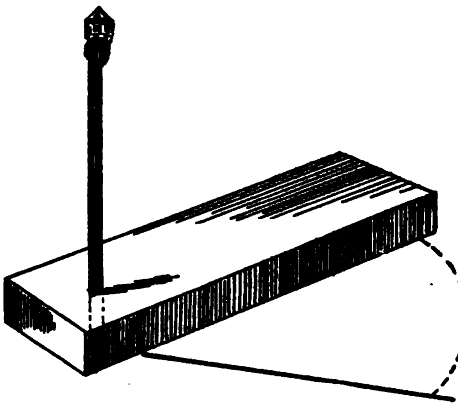
If one of the readings on the horizontal circle H is taken as an origin then the differences between this and the readings for the other faces yield angles which may be denoted by φ, the corresponding readings on the vertical circle V being denoted by ρ.

If the crystal shown in the figure is quartz, there would result for the six vertical faces one common value $\rho = 90°$ and for φ successive values 0°, 60°, 120°, 180°, 240°, 300°, and for the oblique faces the values would be constant for $\rho = 52°$ approx. and for $\varphi = 0°, 60°, 120°, 180°, 240°, 300°$.

Miller's Substitute for a Reflection Goniometer.

When the crystal has bright faces which are too small for the application goniometer the crystal angles may be measured within one degree by an apparatus consisting (Fig. 12) simply of a small rectangular strip of wood say 3″ x 1″ x ¼″ into which has been

FIG. 12.



set perpendicularly a stiff wire about 3″ long, one end of which is pointed and protrudes slightly on the under side to serve as a pivot, the other end is flat. The crystal is attached by wax with the edge to be parallel to the length of the wire. The apparatus is then placed upon a fixed sheet of paper on a horizontal surface, the eye is brought close to the crystal and the apparatus turned on its pivot until the image of some distant object reflected from the face is seen coincident with some near vertical line such as the edge of a window frame.

A line is then ruled on the paper along the edge of the wooden base, and the apparatus is again turned until the same distant object is seen reflected from the second face coincident with the same vertical line. A second line is ruled on the paper along the edge of the base and the angle between these two ruled lines is measured by a protractor and is the supplement angle between the two faces.

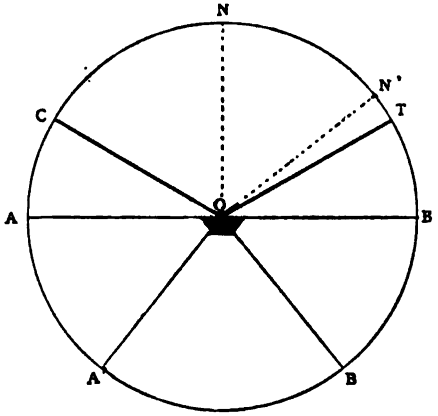
THE ACCURATE* MEASUREMENT OF INTERFACIAL ANGLES.

The angles between smooth bright faces can be measured to half minutes or even closer, as follows:

* The fundamental necessity for good measurement is a good crystal with bright smooth faces. This is more apt to be found among little crystals than large ones.

The crystal is adjusted so that an edge coincides with the axis of rotation O, Fig. 13. CO is a ray of light fixed in direction. OT is the line of sight. NO bisects the angle COT.

Fig. 13.



Whatever the position of the crystal the ray CO striking it is reflected. But only when a face of the crystal coincides with a plane through AB' at right angles to NO, and through the axis of rotation, can the reflection follow the line OT. For a position of the crystal indicated by the black rhomb, one face coincides with AB', and a reflection reaches T. Another face at that time coincides with OB. A reflection will be obtained from this second face, after a rotation measured by the arc BB', the supplement of the arc AB, which measures the angle between the faces.

The axis of rotation may be horizontal or vertical. For most work the latter is preferable.

Fig. 14 shows the simplest form of the Fuess goniometer * (Model 4, a) which is admirably adapted for student work.

Two telescopes are used:

(*a*) The collimator telescope C is fixed in position and guides to the crystal a ray of light from a lamp set at the outer end. At this end is an orifice like a double crescent, Fig. 15, formed by two circular discs of equal diameter set a distance apart which can be regulated by a screw.

(*b*) The observation telescope T, may be set at any angle to C, the axes of T and C always remaining in a horizontal plane and intersecting in the axis of rotation. Within T are two cross hairs, one vertical, the other horizontal.

Before the objective swings an extra lens which, when down, converts the telescope into a weak microscope, and brings the crystal into focus. When it is raised the telescope is focused upon the light.

* R. Fuess, Steglitz, near Berlin, marks 260, or about 65 dollars.

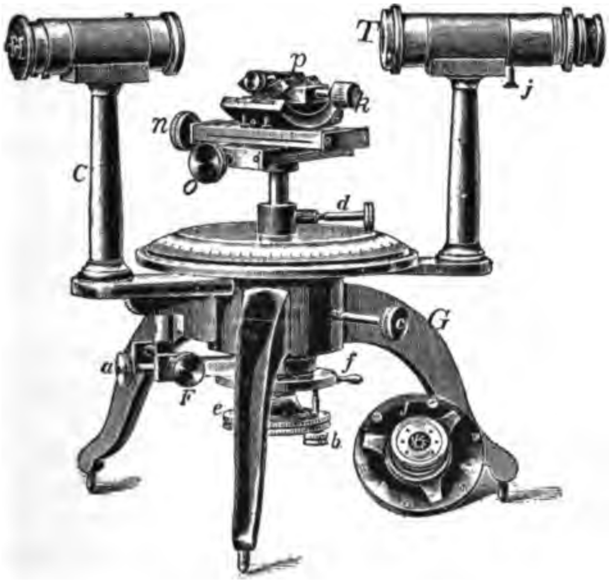
The crystal carrier is shown between the telescopes.

Adjusting the Crystal.

The crystal is carefully cleaned with alcohol and chamois skin and thereafter handled only with forceps. It is attached by wax to the plate *p* as nearly as possible in the correct position. One of the faces of the angle to be measured is placed approximately parallel to one of the sliding screws, for instance *n*, and that screw is placed at right angles to the telescope.

The extra lens is dropped and the crystal raised or lowered into the field by loosening the screw *d*. The edge is then moved by *n*

FIG. 14.

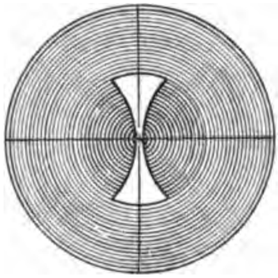


and tipped by the screw *k* of the corresponding circular arc until it appears to coincide with the vertical cross hair. The screw *a* is then loosened and the crystal turned 90° by the pilot wheel *f* and the edge is in turn moved by *o* and tipped by the other circular arc into apparent coincidence with the vertical cross hair. This is repeated by turning back 90° until during a rotation the edge and cross hair appear to coincide.

The extra lens is then raised and if the images of the signal from the faces can be bisected by the cross hairs as in Fig. 15 the adjustment is satisfactory.

The Measuring.

FIG. 15.



The screw G is loosened and the telescope set at some convenient angle to the collimator (100 to 120 degrees). The screw a is then loosened, the graduated circle and crystal are turned together by the pilot-wheel f, until the reflected signal is seen through the telescope, then a is tightened, the signal moved by the tangent screw F until it is bisected by the vertical cross hair, as in Fig. 15, and the vernier is read and recorded.

The screw a is again loosened and the rotation continued until the signal is received from a second face, this is centered by F and a and recorded as before. The difference between the two readings is the supplement angle between the faces.

At least three measurements of any angle should be made * and averaged.

THE SYMMETRY OF CRYSTALS.

There is in almost every crystal a repetition or recurrence of equal angles or similarly grouped faces and to this the name SYMMETRY is given.

This symmetry may be no more than that each face has an opposite parallel face. Such a crystal is said to possess a center of symmetry.†

Or when the crystal is revolved about some particular line each group of faces may recur 2, 3, 4 or 6 times during the revolution. Such a line is called an Axis of Symmetry.‡

Or a plane may so divide the crystal that on each side of that plane there are grouped the same number of faces at the same

* It is sometimes recommended to use different portions of the graduated circle for the three measurements. For instance, for the second measurement when the signal from the second face is centered the screw b is loosened and the crystal alone is turned by the disk e until the signal from the first face is centered, then b is tightened and a loosened and the crystal and circle turned together as before. This is repeated before a third measurement.

† A model is *symmetrical to the center* when every straight line through the center encounters at equal distances on each side of the center two corresponding points.

‡ A model is *symmetrical to an axis* when if revolved about this axis the model reoccupies the same position in space, two, three, four, or six times during one complete revolution. That is, corresponding groups of planes exchange positions after revolutions of 180°, 120°, 90° or 60°.

angles to it and to each other. Such a plane is called a Plane of Symmetry.*

Geometric Symmetry in Models.

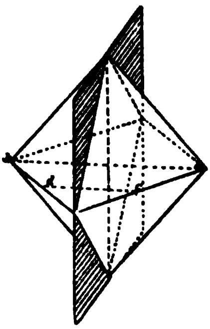
True geometric symmetry to lines and planes is rarely shown by crystals, all that is found is symmetry of *direction* rather than symmetry of *position* and *size* of the bounding faces.

It is convenient, however, in elementary work, to make use of models and drawings of crystals in which all faces symmetrical in direction are made equal in size and at equal distances from the center. Such a shape may be said to be derived from the natural crystal by moving each face parallel to itself until all corresponding faces are at an equal distance from the center. Thus in Fig. 8 the little inner octahedron is the ideal shape of the outer actual crystal, and Fig. 2 is the ideal shape of Fig. 5.

Obtaining the Idea of Symmetry from Models.

In such models and in a few crystals which approximate them in shape the planes and axes of symmetry may be determined by viewing the crystal in different positions and noting the shape and repetition of groups of faces.

FIG. 16.



If, as in Fig. 16, a plane so divides the model that a line from an angle *b* perpendicular to the plane passes through a corresponding angle *a*, or a perpendicular from *c*, the center of an edge, passes through *d*, the center of a similar edge.

Or if in a crystal there is an approximation to this so that a plane appears to divide it into halves symmetrical to each other as *to the number and direction* of their bounding faces, even if there is not strict geometric symmetry, then a probable plane of symmetry has been found.

So also if a model can be revolved about a line, and twice or oftener in a revolution *occupy the same position in space*, or if in a crystal all the planes seen in one position are replaced at other positions by just as many planes which are grouped as in the first set, then a probable axis of symmetry has been determined.

* A model is *symmetrical to a plane* when the plane so divides it that either half is the mirrored reflection of the other, and every line perpendicular to the plane connects corresponding parts and is bisected by the plane of symmetry.

FIG. 17.

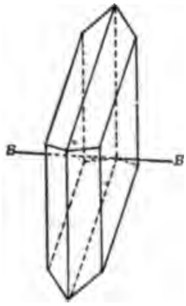
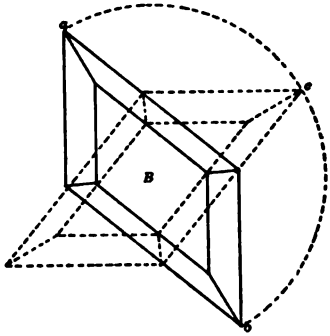


FIG. 18.



For example, the crystal of gypsum, Fig. 17, is symmetrical to the axis *BB*; for, as shown in Fig. 18 both when the point *a* has moved to *b* or again to *a* the crystal occupies the original position in space. Moreover for any intermediate position of *a* such as *c* the space occupied is distinctly not the same. That is, *BB* is an axis of *two-fold or binary* symmetry.

FIG. 19.

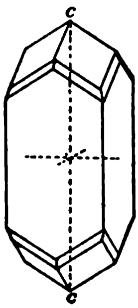


FIG. 20.

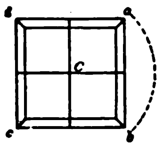


FIG. 21.

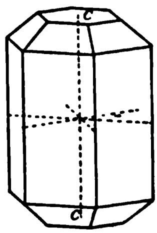
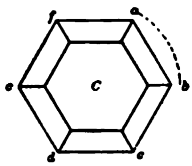


FIG. 22.



The line *CC* in the zircon crystal, Fig. 19, is an axis of *four-fold or tetragonal* symmetry, for, as shown in the horizontal projection, Fig. 20, the crystal occupies the same position in space when any point *a* has moved to *b*, *c*, *d* or again to *a*, and does not for any other position.

Finally the line *CC* in the apatite crystal, Fig. 21, is an axis of *six-fold or hexagonal* symmetry, because, as shown in horizontal projection, Fig. 22, the crystal occupies the same position in space when any point *a* has moved to *b*, *c*, *d*, *e*, *f* or again to *a*.

DETERMINATION OF CRYSTAL SYMMETRY BY MEASUREMENT AND PROJECTION.

With most crystals inspection alone, except as the result of long practice, will not reveal the symmetry of direction which they possess.

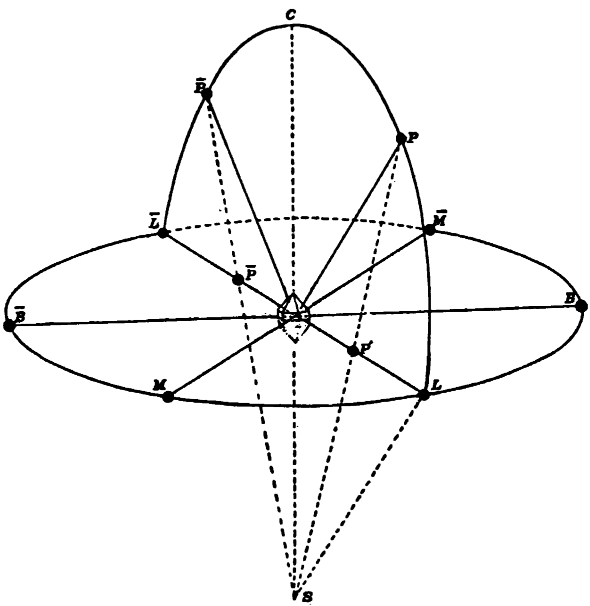
Some simple method is needed by which this symmetry may be found from the angles between the faces and the most satisfactory is to substitute for the solid form a projection upon a plane.

The Method of Stereographic Projection.

The crystal is assumed to be surrounded by a sphere, the centers of the sphere and the crystal coinciding, and radii to be drawn from the center perpendicular to each face of the crystal. The point where any such radius cuts the surface of the sphere is called the pole of the corresponding face.

From each face pole such as *P*, Fig. 23, a line is supposed to be

FIG. 23.



Perspective of a Stereographic Projection.

drawn to the south pole *S*, and the point *P′* where this line pierces the equatorial plane is the stereographic projection of the face pole *P*.

If all the face poles are projected in this way there results a circle dotted with points from the positions of which the symmetry and the angles can be determined.

Thus in Fig. 23 the radii perpendicular to the vertical faces of the quartz crystal lie *in* the equatorial plane and any face pole as

L coincides with its stereographic projection, but the radii perpendicular to an oblique face lie in some meridian plane and any face pole as P is projected at the intersection P' of PS with the equatorial plane.

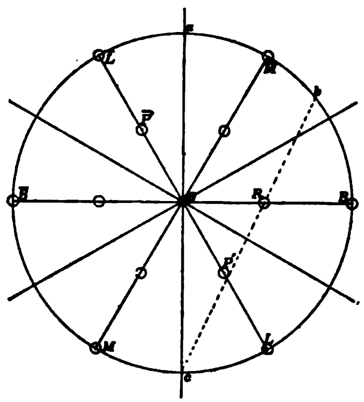
Making a Stereographic Projection.

Preliminary. Select the plane of projection, usually perpendicular to a zone of prominent or numerous faces.

Draw a circle of any convenient diameter, say that of Fig. 26, and let the point B, Fig. 24, be taken as the pole of a chosen vertical face.

Projecting the Vertical Faces. Measure the supplement angles between this face and the other vertical faces and lay off these upon the circumference, thus determining the poles L, M, B, etc.

FIG. 24.



The Angles Needed for Projection of Oblique Faces. The two-circle goniometer yields at once for any face two angles φ and ρ for instance for P, Fig. 23, $\varphi = BL$ and $\rho = CP$. If a two-circle goniometer is not available the same angles may often be obtained.

(a) If P lies in a vertical zone with a vertical face L then ϕ is the same for both and the supplement angle LP is $90° - \rho$.

(b) If P makes equal angles with two vertical faces (say M and B) then ϕ of P is midway between ϕ for M and B and the supplement angle between P and the edge of intersection of the two vertical faces is $90° - \rho$.

(c) If the face lies in two known zones (that is if observation shows the face to make parallel intersections with two other faces and a second set of parallel intersections with two other faces), the two zone circles may be drawn and their intersection will be the desired projection.

Every zone in stereographic projection is a circle and when even two poles of a zone are known a circle may be drawn through them as follows :

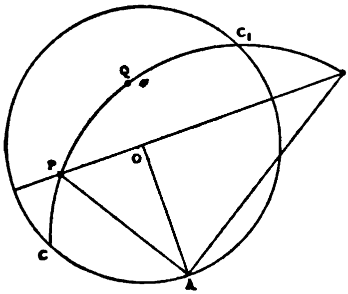
In Fig. 25 given P and Q to find CPC_1.

Draw a diameter through P. The face P_1 opposite P, will be on it.

Draw OA perpendicular to this diameter, draw PA, and from A, a line perpendicular to PA. The intersection of this perpendicular with the diameter through P, will be P_1, the projection of the pole of a face opposite P, that is 180° from P, in the same zone.

The circle through the three points, P, Q and P_1, will be the desired circle.

FIG. 25.

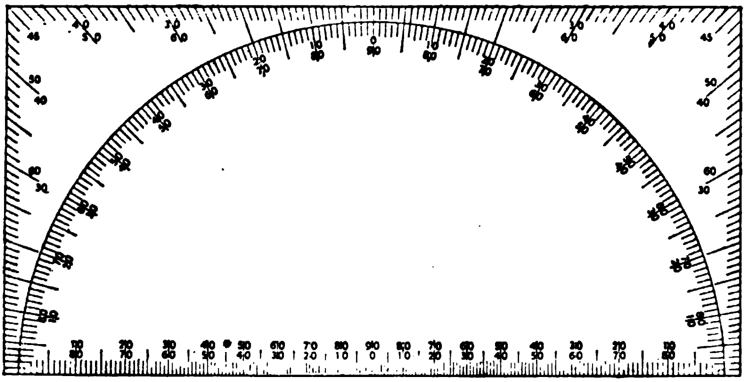


Finding the Projection of the Oblique Face. The desired point lies on the diameter determined by φ and at a distance from the center equal tang $\frac{1}{2}\rho$.

This distance may be found graphically by laying off the arc $ab = \rho$, Fig. 24, drawing bc then is OR the desired distance (the diameters ac and $B\bar{B}$ being perpendicular to each other).

Or the distance may be laid off from the center by a protractor, Fig. 26, devised by Prof. Penfield, in which the values of the stereo-

FIG. 26.



PROTRACTOR NO I, FOR PLOTTING STEREOGRAPHIC PROJECTIONS.
The graduation on the base line gives the stereographically projected degrees.
From * to 0 equals the chord of 90°.

graphically projected degrees have been prepared for a circle of convenient size. Knowing ρ and the diameter on which the pole is projected, the 0° of the base line is placed at the center of the circle and the distance corresponding to ρ (CP) is marked at once.

Judging Symmetry from a Projection.

1. The center of projection is a center of 3, 4 or 6 fold symmetry and the projection may be symmetrical to certain diameters.

Center.	Diameters.	System.	Class of
6 f.	6	HEXAGONAL	DIHEXAGONAL PYRAMID.
4 f.	4 (2 are 4 f. axes)	ISOMETRIC	HEXOCTAHEDRON.
"	" (none are 4 f. axes)	TETRAGONAL	DITETRAGONAL PYRAMID.
3 f.	3 (3 f. axis in plane through each)	ISOMETRIC	HEXOCTAHEDRON* OR HEXTETRAHEDRON.
"	" (no 3 f. axes)	HEXAGONAL	SCALENOHEDRON* OR HEMIMORPHIC.
"	none	ISOMETRIC	DIPLOID.

2. There can be found no axis of 3, 4 or 6 fold symmetry:

Center.	Diameters.	System.	Class of
2 f.	2	ORTHORHOMBIC	PYRAMID.
"	none	MONOCLINIC	PRISM.
not a center of symmetry	1	MONOCLINIC	PRISM.
"	none	TRICLINIC	PINACOID.

Thus in Fig. 24 there is a center of 6-fold symmetry and six diameters of symmetry, hence geometrically the crystal is referred to the class of the dihexagonal pyramid.

This is tentative, other crystals of the same substance may reveal faces which lower the symmetry and indeed the true symmetry of a crystal is known only when all the characters have been considered. Structurally equivalent directions not only imply similar groupings of bounding faces but physical identity in all respects and two directions are not structurally equivalent if in these directions there is revealed any essential difference in behavior with polarized light or etching or pyro-electricity or with any other test, the results of which depend upon the manner the crystal molecules are built together.

The Law of Symmetry.

The Law of Symmetry may be stated as follows:

All crystals of any one substance are of the same grade of symmetry.

That is, in each crystal of the substance, wherever found or under whatever conditions formed, there will be the same number and

* In the classes of the hexoctahedron and scalenohedron each face has an opposite parallel face but in the classes of the hextetrahedron and hemimorphic hexagonal this is not so. The test can usually be made accurately enough by placing any face in contact with a horizontal surface.

arrangement of planes of symmetry and axes of symmetry. The crystals will not all be alike in shape even when the varia-

FIG. 27.

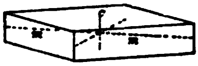


FIG. 28.

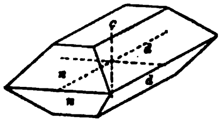
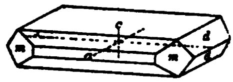


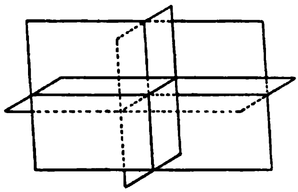
FIG. 29.



tions due to size and to unequal development of faces have been eliminated.

Thus, for instance, Figs. 27 to 29, representing different crystals of the mineral barite ($BaSO_4$), are all symmetrical to three planes placed as in Fig. 30 and to three axes formed by their intersections.

FIG. 30.

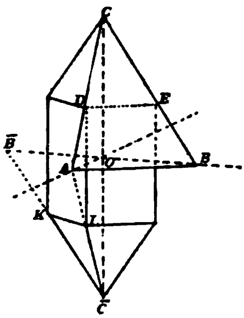


Calcite, $CaCO_3$, occurs in over 200 distinct forms with different angles and in innumerable different combinations of these forms in all of which the symmetry is the same.

Crystallographic Axes.

The position of any plane in space is known if three of its points, not in the same straight line, are known. If three (in one system four) straight lines passing through the center of the crystal are chosen as crystallographic axes than any face *CDE*, Fig. 31, may be defined in position by the distances *OA*, *OB*, *OC*, along these axes from the center to their intersections with the plane *ABC* of which the face *CDE* is a part.

FIG. 31.



If stated as *relative* distances, for instance

$$OA : OB : OC = 0.7 : 1 : 0.82,$$

these intercepts become independent of the absolute position of the face *CDE* and represent any face parallel to it; that is any face at certain angles to the axes however large the crystal may be.

Moreover if the direction from *O* is disregarded they represent other faces $\bar{C}IK$, etc.

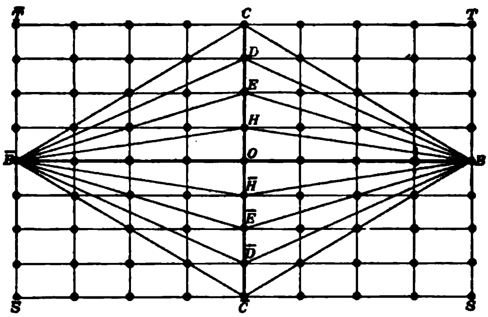
Forms.

Faces such as CDE, $\bar{C}IK$, CDL, etc., which cut the crystal axes at the same relative distances from the center are said to belong to the same "form." The "form" will consist of just enough such faces to satisfy the symmetry of the crystal. If only two faces are required then these two constitute a "form."

The Possible "Forms" on Crystals of One Substance.

Experience proves that well developed faces * upon crystals of the same substance occur at particular angles dependent upon the structure. For instance, if the ultimate particles in a plane through two of the chosen axes $B\bar{B}$ and $C\bar{C}$ were as in Fig. 32, then the most probable faces would be those passing through the greatest number of points, that is, the directions $T\bar{T}$, TS and BC (or $\bar{B}C$).

FIG. 32.



The next in probability would be BE (or $B\bar{E}$) and still less probable BD (or $\bar{B}D$) and BH (or $B\bar{H}$).

These directions would be absolutely determined if the relative distances apart of consecutive points on $C\bar{C}$ and $B\bar{B}$ were known. In the figure these are 3 : 5, hence the angles with $B\bar{B}$ are:

Direction.	Natural tangent.	Angle.
$T\bar{T}$	$1 \div \infty \quad = 0$	180°
TS	$\infty : 1 \quad = \infty$	90°
BC	$4 \times 3 : 4 \times 5 = 0.6$	30° 58′
BE	$2 \times 3 : 4 \times 5 = 0.3$	16° 42′
BD	$3 \times 3 : 4 \times 5 = 0.45$	26° 45′
BH	$1 \times 3 : 4 \times 5 = 0.15$	8° 32′

The Fundamental Law of Rational Intercepts.

In the example given if the intercepts on $B\bar{B}$ and $C\bar{C}$ are re-

* There exist minute so-called "vicinal" planes which are not solely the results of cohesive attraction, but also of disturbing causes such as concentration currents. See Gaubert, *Bull. Soc. Franc.*, Vol. 27, pp. 6–48.

duced so that for each direction one term, for instance the intercept on $C\bar{C}$, is unity the other terms bear a very simple relation to each other. Any one is a simple multiple or factor of any other. For *BC*, *BE*, *BD*, *BH* the intercepts on *BB* are relatively 60 : 30 : 45 : 15 or 4 : 2 : 3 : 1.

Such a simple relation is found always to exist for faces which are true crystal faces and it has been expressed as follows:

In all crystals of the same chemical substance, if the intercepts of ANY *face upon the crystallographic axes are divided, term by term, by the corresponding intercepts of* ANY OTHER *face, the quotients will always be simple rational numbers or infinity.*

For instance in a certain substance the three axes are cut by two faces in distances which after reduction are

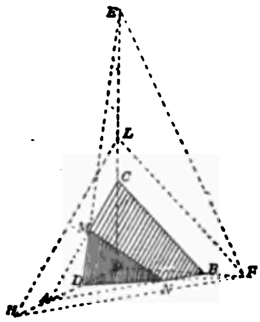
$$0.813 : 1 : 1.903$$
$$1.626 : 1 : 5.709.$$

Dividing the second by the first, term by term, there result 2, 1, 3. A face with intercepts relatively 1.734 : 1 : 6.275 *could not occur upon this crystal or upon any other crystal of this substance* because $\frac{1.734}{0.813} = 2.1328 +$ and $\frac{6.275}{1.903} = 3.2973 +$ that is, the quotients obtained by dividing corresponding terms are not simple numbers or infinity.

The Weiss Symbols.

In order to compare the intercepts of the different faces of a crystal Prof. Weiss designated the values of the intercepts *AO*, *OB*, and *OC* of some chosen face *BCMN*, Fig. 33, by *a*, *b* and *c* respectively and the face by the symbol $a : b : c$.

FIG. 33.



Then according to the law of rational intercepts, any other possible face on that crystal as *MND* would have such intercepts that divided term by term the quotients would be simple rational numbers or infinity. In this case it is at once seen by drawing *FHL* parallel to *BCMN*, since the symbol of *FHL* is also $a : b : c$, that the symbol of *MND* is $\frac{1}{3}a : b : 2c$, which may be written $a : 2b : 6c$.

The Miller Indices.

The symbols of Weiss* have been very generally superseded by condensed expressions which are more convenient for purposes of calculation. Chief among these are the so-called Miller Indices.

In these the chosen or unit face is assumed to be moved parallel to itself until it is outside of all the other faces, then the intercepts of these faces are all fractional parts of the unit intercepts.

If then these fractions, written in the order of the axes OA, OB, OC, are reduced by dividing each by the least common multiple of the numerators there result three fractions $\frac{1}{h}, \frac{1}{k}, \frac{1}{l}$. The denominators of these fractions are the Miller indices, that is hkl is the general Miller symbol for any face.

It is no harder to realize the position of a face from an expression 1 2 3 than from the equivalent $a : \frac{1}{2}b : \frac{1}{3}c$. Each means that the intercepts *in comparison to the intercepts of the chosen unit face and in the same order* are the same length, half as long and one third as long.

Choosing Crystallographic Axes.

It is always possible and indeed essential to choose as crystallographic axes those lines which are closely related to the symmetry of the crystal. The choice should be made in the following order:

First, axes of symmetry.

Second, lines perpendicular to planes of symmetry.

Third, lines parallel or equally inclined to several faces of the crystal.

In some crystals there may be more lines of equal prominence than are needed. Preference should then be given:

(*a*) To directions at right angles to each other.

(*b*) To interchangeable directions, that is to directions such that the grouping of the faces about one is the same as the grouping of the faces about the other.

The Six Systems.

The six systems already mentioned under symmetry may then

* Weiss coefficients and Miller indices are essentially reciprocals of each other. For instance, a plane with indices (4 3 2) means $\frac{1}{4}a : \frac{1}{3}b : \frac{1}{2}c$, and making a, for instance, unity, we have $a : \frac{4}{3}b : 2c$ as the Weiss symbol. Conversely, a plane with a symbol $5a : b : \frac{5}{3}c$ is first reduced to $a : \frac{1}{5}b : \frac{1}{3}c$; then, taking reciprocals, (1 5 3) is the Miller symbol.

be defined each as including all crystals which are, by the given rules, referred to a particular set of axes:

THE TRICLINIC SYSTEM.—Three non-interchangeable axes at oblique angles to each other.

THE MONOCLINIC SYSTEM.—Three non-interchangeable axes two of which are oblique to each other, the third is at right angles to the other two.

THE ORTHORHOMBIC SYSTEM.—Three axes at right angles but not interchangeable.

THE TETRAGONAL SYSTEM.—Three axes at right angles, of which two are interchangeable.

THE HEXAGONAL SYSTEM.—Four axes, three of which lie in one plane at sixty degrees to each other and are interchangeable, the fourth is at right angles to the other three.

THE ISOMETRIC SYSTEM.—Three interchangeable axes at right angles to each other.

Determination of Type Symbols by Inspection.

After the axes have been chosen, as described and placed in the conventional positions stated under each system, the determination of the type symbols may be conducted as follows in models and large crystals:

Place a straight edge or pencil in contact with a face and turn the straight edge always as a line *in* the face until its relation to each axis has been noted. The absolute values of the axial intercepts are not needed to determine the *type* of form; all that is essential is to note parallelism and equality.

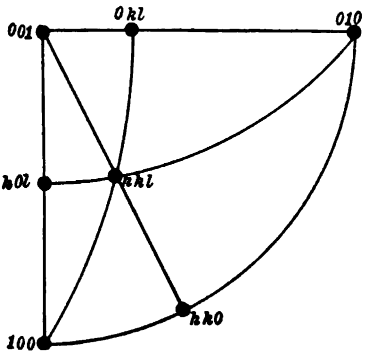
If it is not evident that all the faces of the figure hold the same relation to the axes, any supposedly different face is tried in precisely the same way with the straight edge and with respect to the *same* axes. If, when the face is parallel to one of the axes, the corresponding index is designated o in Miller or by ∞ in Weiss, we will have seven possible type symbols:

		MILLER. Unit (111)	WEISS. Unit $a : b : c$
1. The face cuts all axes		hkl	$na : b : mc$
2. " " is parallel	$A\bar{A}$	okl	$\infty a : b : mc$
3. " " " "	$B\bar{B}$	hol	$a : \infty b : mc$
4. " " " "	$C\bar{C}$	hko	$na : b : \infty c$
5. " " " "	$A\bar{A}$ and $B\bar{B}$	001	$\infty a : \infty b : c$
6. " " " "	$A\bar{A}$ " $C\bar{C}$	010	$\infty a : b : \infty c$
7 " " " "	$B\bar{B}$ " $C\bar{C}$	100	$a : \infty b : \infty c$

Determination of Type Symbols in a Stereographic Projection.

If measurements have been made the resulting stereographic projection yields the same seven type symbols, 5, 6 and 7, being each limited to one form, but the other types including more than one form according to the values of the intercepts. The position of the forms for one particular ratio *hkl* in a system with the crystallographic axes at right angles, is shown in Fig. 34.

FIG. 34.



CHAPTER II.

TRICLINIC SYSTEM.*

THE Triclinic System includes two classes in both of which the crystallographic axes are three lines oblique to each other and not interchangeable.

PINACOIDAL CLASS. 2.

No. 31. Holohedry, *Liebisch.* No. 31. Normal Class, *Dana.*

Choosing Crystallographic Axes.

Usually the intersections of three prominent faces are chosen as axes and one is conventionally made the vertical axis c, the others the macro or $\bar{b}$ axis and the brachy or $\breve{a}$ axis.

The Seven Type Forms.

Each form consists of two parallel faces as follows:

1. TETRAPYRAMID.—$n\breve{a} : \bar{b} : m\acute{c}$; $\{hkl\}$.

Two parallel faces which intersect all axes, Fig. 35. For any set of intercepts four independent forms result which if combined make a complete triclinic pyramid as shown in Fig. 36. Fig. 43

FIG. 35.

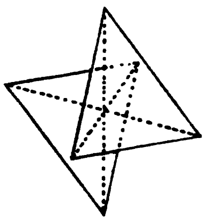


FIG. 36.

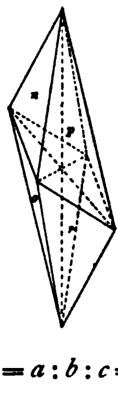
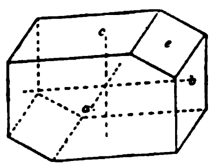


FIG. 37.



shows two tetra-pyramids $p' = a : b : c = 111$ and $'p = a : b' : c = 1\bar{1}1$ of the mineral axinite.

* Also known as Tetarto prismatic, Ein-und-eingliedrige, Triclinohedral, Clinorhomboidal, Anorthic, Doubly oblique and Asymmetric.

2. HEMI BRACHY DOME.— $\infty \breve{a} : \bar{b} : mc$; $\{okl\}$.

Two faces each parallel to the brachy axis. The face *e* and its opposite, Fig. 37, modifying the three pinacoids.

3. HEMI MACRO DOME.—$\breve{a} : \infty \bar{b} : mc$; $\{hol\}$.

Two faces each parallel to the macro axis. The face *d* and its opposite, Fig. 38, modifying the pinacoids.

4. HEMI PRISM.—$n\breve{a} : \bar{b} : \infty c$; $\{hko\}$.

Two faces each parallel to the vertical axis. The face *m* and its opposite, Fig. 39, modifying the pinacoids.

5. BASAL PINACOID.— $\infty \breve{a} : \infty \bar{b} : c$; $\{001\}$.

Two faces each parallel to both the macro and brachy axes. The faces *c* in Figs. 38 to 40.

FIG. 38.

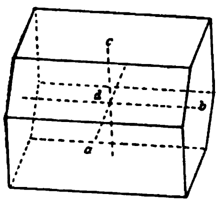


FIG. 39.

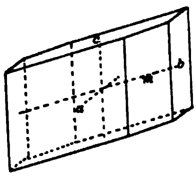
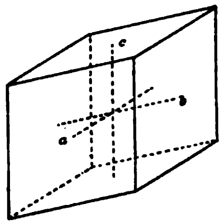


FIG. 40.



6. BRACHY PINACOID.—$\infty \breve{a} : \bar{b} : \infty c$; $\{010\}$.

Two faces, each parallel to the brachy and vertical axes. The faces *b* of Figs. 38 to 40.

7. MACRO PINACOID.—$\breve{a} : \infty \bar{b} : \infty c$; $\{100\}$.

Two faces each parallel to the macro and vertical axes. The faces *a* of Figs. 38 to 40.

Combinations in the Triclinic System.

Fig. 41 shows a crystal of chalcanthite with brachy pinacoid *b*,

FIG. 41.

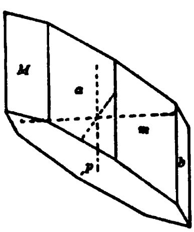


FIG. 42.

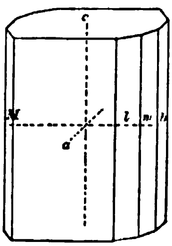
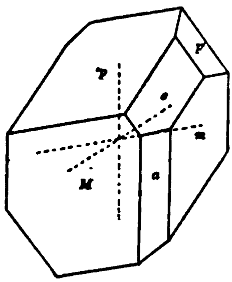


FIG. 43



macro pinacoid *a*, right hemi prism *m*, left hemi prism *M* and lower left tetra pyramid *'p*. Fig. 42 shows a crystal of cyanite with the three pinacoids *a*, *b* and *c*, the right *m*, and left *M* hemi unit prisms and a right hemi brachy prism $l = (2\breve{a} : \bar{b} : \infty c)$; $\{120\}$.

Fig. 43 shows a crystal of axinite with both hemi prisms *m* and *M*, macro pinacoid *a*, upper right and upper left unit pyramids *p'* and *'p* and a macro dome $e = (\breve{a} : \infty \bar{b} : 2c.)$; $\{201\}$.

Other Classes in Triclinic System.

One other class known as the unsymmetrical class exists and in this each form is a single face. No examples among minerals are known but among salts there is calcium thiosulfate, $CaS_2O_3 \cdot 6H_2O$.

CHAPTER III.

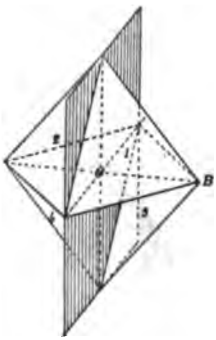
MONOCLINIC SYSTEM.*

THE monoclinic system includes three classes of symmetry, in all of which the crystallographic axes may be chosen so that two are oblique to each other and the third normal to the other two. The axes are not interchangeable.

PRISMATIC CLASS. 5.

No. 28. Holohedry, *Liebisch*. No. 28. Normal Group, *Dana*.

FIG. 44.



All the common monoclinic minerals occur in crystals symmetrical to one plane and to one axis at 90° to the plane, Fig. 44.

Choosing Crystallographic Axes.

The axis of symmetry is always chosen as the axis $\bar{b}$ and placed horizontally from right to left.

Two other axes, oblique to each other, are chosen† *in the plane* of symmetry one of which is placed vertically and denoted by $\dot{c}$ the other $\grave{a}$ "the clino" dips downward from back to front. The acute angle between the vertical and clino axis is called β.

Tabulation of the Seven Type Forms.

NAME.	FACES.	WEISS.	MILLER.
Each face intersects all axes :			
1. HEMI PYRAMID,	4	$n\grave{a} : \bar{b} : m\dot{c}$	$\{hkl\}$
Each face parallel to one axis :			
2. CLINO DOME,	4	$\infty\grave{a} : \bar{b} : m\dot{c}$	$\{0kl\}$
3. HEMI ORTHO DOME,	2	$\grave{a} : \infty\bar{b} : m\dot{c}$	$\{h0l\}$
4. PRISM,	4	$n\grave{a} : \bar{b} : \infty\dot{c}$	$\{hk0\}$
Each face parallel to two axes :			
5. BASAL PINACOID,	2	$\infty\grave{a} : \infty\bar{b} : c$	$\{001\}$
6. CLINO PINACOID,	2	$\infty\grave{a} : \bar{b} : \infty\dot{c}$	$\{010\}$
7. ORTHO PINACOID,	2	$\grave{a} : \infty\bar{b} : \infty\dot{c}$	$\{100\}$

* Also called Hemiprismatic, Zwei-und-eingliedridge, Monoclinohedral, Clinorhombic, Monosymmetric.

† For instance the intersections of the pinacoids would determine both directions, or the edges of any prism and any clino dome would determine both directions.

Description of the Type Forms.

1. Hemi Pyramid.—$n\grave{a} : b : mc$; $\{hkl\}$.

Four faces each intersecting all the axes in distances not simple multiples of each other. Fig. 45 shows a negative form cut off by a positive ortho dome *o*.

For any set of intercepts two independent forms result which combined form a complete pyramid. For instance the combination of $\bar{p}$, Fig. 45, with the corresponding positive form p gives Fig. 46.

Fig. 45.

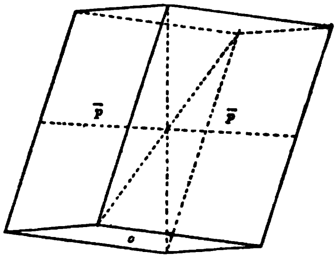
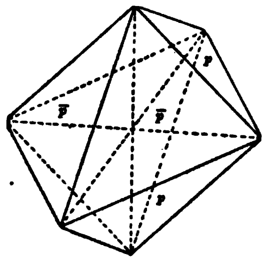


Fig. 46.



2. Clino Dome.—$\infty\grave{a} : \bar{b} : mc$; $\{0kl\}$.

Four faces, each parallel to the clino axis and cutting the vertical and ortho axes in distances *not* simply proportionate. The faces *d* of Fig. 47 combined with two pinacoids.

3. Hemi Ortho Dome.—$\grave{a} : \infty\bar{b} : c$; $\{h0l\}$.

Two opposite faces, each parallel to the ortho axis and cutting the clino and vertical axes in distances not simply proportionate. The faces *o* in Figs. 45 and 48 are the positive hemi ortho dome. Another independent form exists with the same intercepts.

Fig. 47.

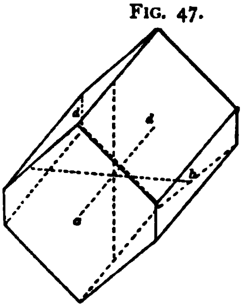


Fig. 48.

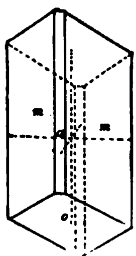
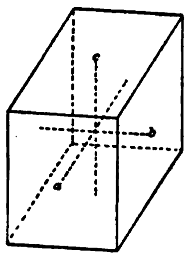


Fig. 49.



4. Prism.—$n\grave{a} : \bar{b} : \infty c$; $\{hk0\}$.

Four faces, each parallel to the vertical axis, and cutting the

basal axes in distances not simply proportionate. The faces *m* in Fig. 48 and subsequent figures.

5. BASAL PINACOID.—$\infty\grave{a}:\infty\bar{b}:c$; $\{001\}$.

Two faces, each parallel to both basal axes. The faces *c* of Fig. 49 and subsequent figures.

6. CLINO PINACOID.—$\infty\grave{a}:\bar{b}:\infty c$; $\{010\}$.

Two faces, each parallel to the clino and vertical axes. The faces *b* of Fig. 49 and subsequent figures.

7. ORTHO PINACOID.—$\grave{a}:\infty\bar{b}:\infty c$; $\{100\}$.

Two faces, each parallel to the ortho and vertical axes. The faces *a* of Fig. 49 and subsequent figures.

Combinations in the Prismatic Class.

Pyroxene.—Axes $\grave{a}:\bar{b}:c = 1.092:1:0.589$; $\beta = 74° 10' 9''$.

Fig. 50 shows the three pinacoids, *a*, *b* and *c*, the unit prism *m*, the negative unit hemi-pyramid $\bar{p}$ and the positive hemi-pyramid $v = (\grave{a}:\bar{b}:2c)$; $\{221\}$. Fig. 52 is the same without *v* and Fig. 51 omits also the basal pinacoid *c*. Fig. 53 shows the unit prism *m*, the

FIG. 50.

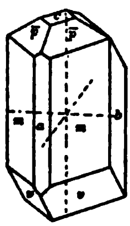


FIG. 51.

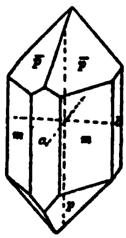


FIG. 52.

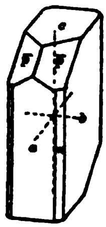
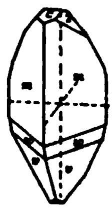


FIG. 53.



basal pinacoid *c*, two positive hemi-pyramids *v* and $w = (\grave{a}:\bar{b}:3c)$; $\{331\}$; and a clino dome $z = (\infty\grave{a}:\bar{b}:2c)$; $\{021\}$.

AMPHIBOLE.—Axes $\grave{a}:\bar{b}:c = 0.551;1:0.293$; $\beta = 73° 58' 4''$.

FIG. 54.

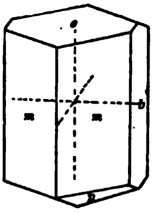


FIG. 55.

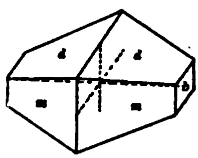


FIG. 56.

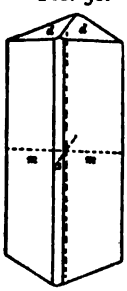


Fig. 54 shows the unit prism m, the basal and clino pinacoids, c and b and the positive unit hemi pyramid p. Fig. 55 shows the unit prism, clino pinacoid and unit clino dome $d = (\infty \grave{a} : \bar{b} : c)$. $\{011\}$. Fig. 56 shows the same except that the clino pinacoid b is replaced by the ortho pinacoid a.

FIG. 57.

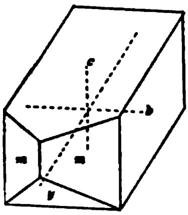


FIG. 58.

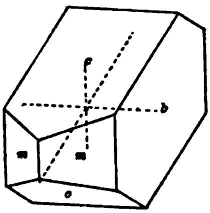


FIG. 59.

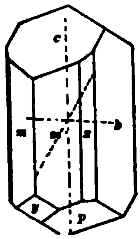
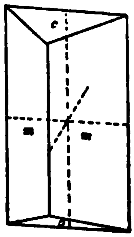


FIG. 60.



ORTHOCLASE.—Axes $\grave{a} : \bar{b} : c = 0.658 ; 1 : 0.555 ; \beta = 63° 56' 46''$.

Fig. 57 shows the unit prism m, clino and basal pinacoids b and c, and positive hemi orthodome $y = (\grave{a} : \infty \bar{b} : 2c)$; $\{201\}$. In Fig. 58 y is replaced by $o = (\grave{a} : \infty \bar{b} : c)$; $\{101\}$ and in Fig. 60 the clino pinacoid is omitted. Fig. 59 includes the forms of 57 and also a clino prism $z = (3\grave{a} : \bar{b} : \infty c)$; $\{130\}$ and the unit pyramid p.

Other Classes in the Monoclinic System.

Two other classes are known:

3. CLASS OF THE MONOCLINIC SPHENOID. With one axis of 2-fold symmetry.

No examples among minerals are known. Examples in salts are tartaric acid and cane-sugar, $C_{12}H_{22}O_{11}$.

4. CLASS OF THE MONOCLINIC DOME. With one plane of symmetry.

Examples: The rare minerals clinohedrite and scolecite.

CHAPTER IV.

ORTHORHOMBIC SYSTEM.

THE orthorhombic * system includes three classes of symmetry, in all of which the crystallographic axes may be chosen at right angles to each other, but are not interchangeable.

In this system of moderate symmetry certain facts common to all crystals can be better illustrated and understood than in the other systems. Two of these are discussed under the headings "Series" and "Symbols for Individual Faces."

Series.

All forms which ever appear upon crystals of the same substance belong to one series. That is, their faces occur at such angles that if one of the faces is taken as the unit and its intercepts expressed by $\breve{a} : \bar{b} : \dot{c}$ all other faces may be simply expressed in terms of this face. For instance in the crystals of topaz, Figs. 78 to 80, the calculated intercepts for certain faces and their symbols, when p is taken as the unit face, are as follows:

FACE.	CALCULATED INTERCEPTS.	SYMBOLS IN TERMS OF p.	
p	0.528 : 1 : 0.477	$\breve{a} : \bar{b} : \dot{c}$	{111}
i	0.528 : 1 : 0.318	$\breve{a} : \bar{b} : \frac{2}{3}\dot{c}$	{223}
q	0.528 : 1 : 0.954	$\breve{a} : \bar{b} : 2\dot{c}$	{221}
m	0.528 : 1 : ∞	$\breve{a} : \bar{b} : \infty\dot{c}$	{110}
l	1.156 : 1 : ∞	$2\breve{a} : \bar{b} : \infty$	{120}
f	∞ : 1 : 0.954	$\infty\breve{a} : \bar{b} : 2\dot{c}$	{021}
h	1 : ∞ : 0.318	$\breve{a} : \infty\bar{b} : \frac{2}{3}\dot{c}$	{203}

Symbols for Individual Faces.

For correct projection and for use in calculation face symbols are needed which show the particular angle in which the face occurs. These are simply obtained by considering positive and negative directions upon the crystal as in the figure. Then the different faces of Fig. 61, for which the form symbol is $n\breve{a} : \bar{b} : m\dot{c}$ or $\{hkl\}$, have their individual symbols, (hkl), $(h\bar{k}l)$, $(h\bar{k}\bar{l})$, $(hk\bar{l})$, the minus signs indicating the negative direction and the paren-

* Also called Prismatic, Rhombic, Ein-und-einaxige, Anisometric and Trimetric.

theses ( ) typifying a face as opposed to { } for a form. Or in Weiss's Symbols the equivalents may be obtained either by use of minus signs or a (′) prime upon the negative intercept thus the equivalent for $(h\bar{k}l)$ would $n\breve{a} : \bar{b}' : m\dot{c}$.

PYRAMIDAL CLASS. 8.

No. 25. Holohedry, *Liebisch*. No. 25. Normal Group, *Dana*.

Almost all orthorhombic minerals crystallize in forms symmetrical to three planes at right angles to each other, as in Fig. 62, the intersections of these being axes of two-fold symmetry.

FIG. 61.

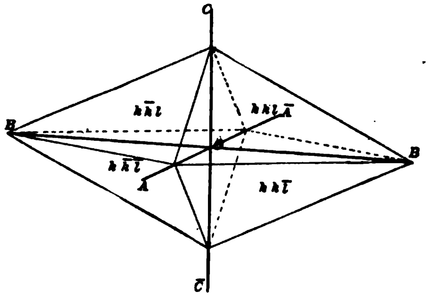
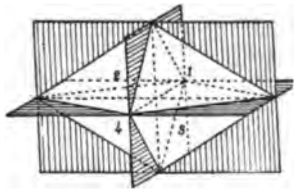


FIG. 62.



Choosing Crystallographic Axes.

The axes of symmetry are the crystallographic axes. One, *c*, is placed vertically. Of the two others the one on which the intercept *of the chosen unit face* is the longer, is placed from left to right, and called the *macro* or $\bar{b}$ axis; the other axis, placed from front to back, is called the *brachy* or $\breve{a}$ axis.

The unit face chosen will if possible be a face of frequent occurrence which intersects all the axes, or on account of similarity of crystals to some species of related composition, another choice may be made or the values $\breve{a}$, $\bar{b}$ and $\dot{c}$ may result from two different faces or from cleavages.

Tabulation of the Seven Type Forms.

NAME.	FACES.	WEISS.	MILLER.
Each face intersects all axes:			
1. RHOMBIC PYRAMID.	8	$n\breve{a} : \bar{b} : m\dot{c}$	hkl}
Each face parallel to one axis:			
2. BRACHY DOME.	4	$\infty\breve{a} : \bar{b} : m\dot{c}$	{okl}
3. MACRO DOME.	4	$\breve{a} : \infty\bar{b} : m\dot{c}$	{hol}
4. RHOMBIC PRISM.	4	$n\breve{a} : \bar{b} : \infty\dot{c}$	{hko}

Name.	Faces.	Weiss.	Miller.
Each face parallel to two axes:			
5. Basal Pinacoid.	2	$\infty\breve{a} : \infty\bar{b} : \dot{c}$	$\{001\}$
6. Brachy Pinacoid.	2	$\infty\breve{a} : \bar{b} : \infty\dot{c}$	$\{010\}$
7. Macro Pinacoid.	2	$\breve{a} : \infty\bar{b} : \infty\dot{c}$	$\{100\}$

Description of the Type Forms.

1. Rhombic Pyramid.—$n\breve{a} : \bar{b} : mc$; $\{hkl\}$.

Eight faces, each of which cuts the three axes in the same relative distances, which are never simple multiples of each other. In the ideal forms the faces are equal scalene triangles.

A pyramid may be composed either of faces with the unit intercepts, or the faces may be at other angles, with any one or two of the intercepts simple multiples of the unit intercepts.

For instance if in the series of figures 63 to 67 the faces p constitute the unit pyramid $\breve{a} : \bar{b} : \dot{c}$; $\{111\}$; then a series of pyramids which might occur with this would have different symbols and names. The pyramid s, shown in Fig. 63 enclosing p and in Fig.

Fig. 63.

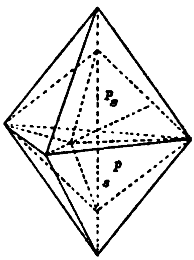


Fig. 64.

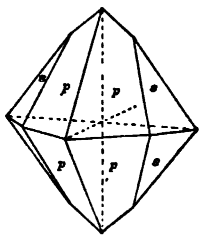


Fig. 65.

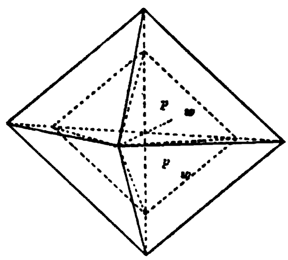


Fig. 66.

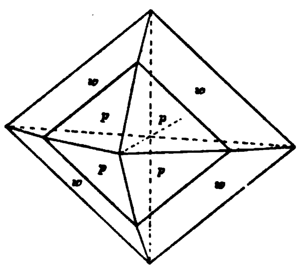
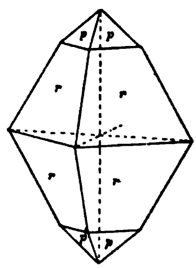


Fig. 67.



64 combined with p; would be called a *brachy* pyramid, its symbol being $2\breve{a} : \bar{b} : \frac{3}{2}c$; $\{364\}$.

The pyramid *w* shown in Fig. 65 enclosing *p* and in Fig. 66 combined with *p* would be called a *macro* pyramid, its symbol being $\breve{a} : \frac{3}{2}\bar{b} : \frac{3}{2}c$; {322}; and the pyramid *r* shown in Fig. 67 combined with *p* would be called a unit series pyramid, its symbol being $\breve{a} : \bar{b} : 2c$; {221}.

2. Brachy Dome.—$\infty\breve{a} : \bar{b} : mc$; {0*kl*}.

Four faces, each parallel to the brachy axis but cutting the macro axis and vertical axis in distances *not* simply proportionate. The faces *d* in Fig. 68.

3. Macro Dome.—$\breve{a} : \infty\bar{b} : mc$; {*h*0*l*}.

Four faces, each parallel to the macro axis but cutting the brachy axis and the vertical axis in distances *not* simply proportionate. The faces *o* in Fig. 69.

Fig. 68.

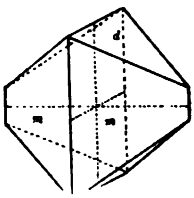
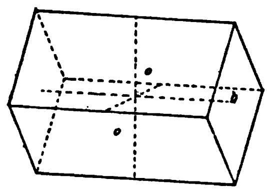


Fig. 69.



4. Rhombic Prism.—$n\breve{a} : \bar{b} : \infty c$; {*hk*0}.

Four faces, each parallel to the vertical axis and cutting the basal axes in distances *not* simply proportionate.

The intercepts on the basal axes may be in the unit ratio or

Fig. 70.

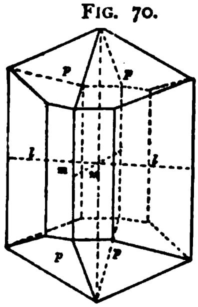
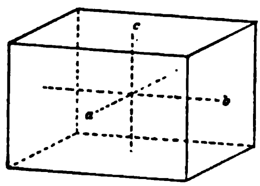


Fig. 71.



one of the intercepts may be *relatively* lengthened just as in the pyramids.

The faces *m* in Fig. 68. In Fig. 70 if *p* is the unit pyramid then, relatively, *m* is the unit prism $\breve{a} : \bar{b} : \infty c$; {110}; and *l* is a brachy prism $2\breve{a} : b : \infty c$; {120}.

5. BASAL PINACOID.—$\infty\breve{a} : \infty\bar{b} : c$; {001}.

Two faces, each parallel to the basal axes. The faces c in Figs. 71–80.

6. BRACHY PINACOID.—$\infty\breve{a} : \bar{b} : \infty c$; {010}.

Two faces, each parallel to the brachy and vertical axes. The faces b in Figs. 69 and 71.

7. MACRO PINACOID.—$\breve{a} : \infty\bar{b} : \infty c$; {100}.

Two faces, each parallel to the macro and vertical axes. The faces a in Fig. 71.

Combinations in the Pyramidal Class.

Barite.—Axes $\breve{a} : \bar{b} : c = 0.815 : 1 : 1.313$.

The prevailing faces are the unit prism m, the basal pinacoid c, the macro dome $n = (\breve{a} : \infty\bar{b} : \frac{1}{2}c)$; {102}; and the brachy dome $d = (\infty\breve{a} : \bar{b} : c)$; {011}.

FIG. 72.

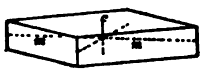


FIG. 73.

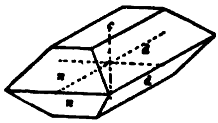


FIG. 74.

FIG. 75.

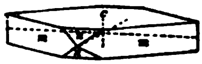


FIG. 76.

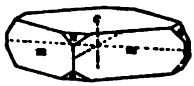
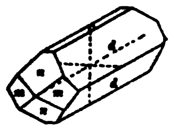


FIG. 77.



All of these are shown in Fig. 77. Fig. 76 contains also the brachy pinacoid b and Fig. 74 the macro pinacoid a. Figs. 72, 73 and 75 are simpler combinations of the same forms.

Topaz.—Axes $\breve{a} : \bar{b} : c = 0.528 : 1 : 0.477$.

FIG. 78.

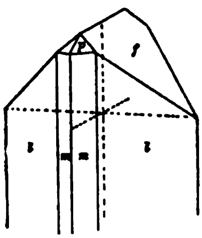


FIG. 79.

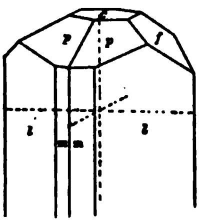


FIG. 80.

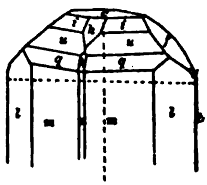


Fig. 78 shows the unit pyramid p, unit prism m, brachy prism $l = (2\breve{a} : \bar{b} : \infty c)$; {120}; and the brachy dome $f = (\infty\breve{a} : \bar{b} : 2c)$;

{021}. Fig. 79 shows the same forms with the basal pinacoid c and Fig. 80 shows all of 79 and also two other pyramids $i = (\breve{a} : \bar{b} : \tfrac{2}{3}c)$; {223}; $q = (\breve{a} : \bar{b} : 2c)$; {221}; and two macro-domes $h = (\breve{a} : \infty \bar{b} : \tfrac{2}{3}c)$; {203}; and $k = (\breve{a} : \infty \bar{b} : 2c)$; {201}.

OTHER CLASSES OF THE ORTHORHOMBIC SYSTEM.

6. CLASS OF THE RHOMBIC SPHENOID.—With three axes of two-fold symmetry at 90° to each other. Examples—Epsomite and goslarite.

7. HEMIMORPHIC CLASS.—With two planes of symmetry at 90° to each other, intersecting in an axis of two-fold symmetry. Examples—Calamine, stephanite and prehnite.

CHAPTER V.

TETRAGONAL SYSTEM.*

In all Tetragonal forms the crystallographic axes can be chosen at right angles to each other and so that two will be interchangeable, that is will be surrounded by exactly the same number of faces and with corresponding faces at the same angles. The grouping of faces about the third axis will not be the same as to angles and not necessarily the same as to number of faces.

Series.

A substance can only occur in forms of one class and in forms of *one series* in that class.

Because of the two interchangeable axes the intercepts of any face upon these will be simple multiples of each other. The intercept upon the vertical axis will bear no simple relation to these but *when two different faces are compared* there will be found a simple relation between the corresponding intercepts of all three axes.

Thus for zircon the common forms are p, m, u and x of Figs. 89 to 92. For these the intercepts and the symbols, if p be taken as the unit, are:

p	$1:1:0{,}64 = a:a:c$;	$\{111\}$
m	$1:1:\infty \quad = a:a:\infty c$;	$\{110\}$
u	$1:1:1.92 = a:a:3c$;	$\{331\}$
x	$1:3:1.92 = a:3a:3c$;	$\{311\}$

CLASS OF THE DITETRAGONAL PYRAMID. 15.

No. 18. Holohedry, *Liebisch*. No. 6. Normal, *Dana*.

Symmetry of the Class.

Forms in this class are symmetrical to one conventionally horizontal plane and to four vertical planes at forty-five degrees to each other, Fig. 81. The intersections of these planes with each other are axes of symmetry and of these *CC* is an axis of fourfold symmetry.

* Also called Pyramidal, Viergliedrige, Zwei-und-einaxige, Monodimetric, Quadratic and Dimetric.

Choosing Crystallographic Axes.

The axis of fourfold symmetry is chosen as the vertical axis *c* and either pair of alternate horizontal axes as the interchangeable axes *a*.

FIG. 81.

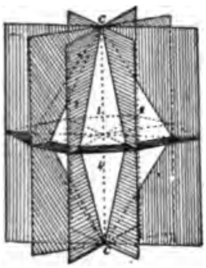
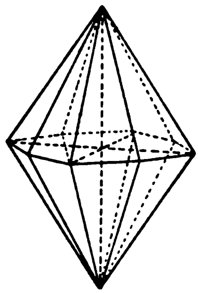


FIG. 82.



Tabulation of the Seven Type Forms.

NAME.	FACES.	WEISS.	MILLER.
Each face oblique to *c*.			
1. DITETRAGONAL PYRAMID.	16	$a : na : mc$	$\{hkl\}$
2. PYRAMID OF SECOND ORDER.	8	$a : \infty a : mc$	$\{h0l\}$
3. PYRAMID OF FIRST ORDER.	8	$a : a : mc$	$\{hhl\}$
Each face horizontal.			
4. BASAL PINACOID.	2	$\infty a : \infty a : c$	$\{001\}$
Each face vertical.			
5. DITETRAGONAL PRISM.	8	$a : na : \infty c$	$\{hk0\}$
6. PRISM OF SECOND ORDER.	4	$a : \infty a : \infty c$	$\{100\}$
7. PRISM OF FIRST ORDER.	4	$a : a : \infty c$	$\{110\}$

Description of the Type Forms.

1. DITETRAGONAL PYRAMID. — $a : na : mc$; $\{hkl\}$.

Sixteen faces, Fig. 82, each cutting the two basal axes at unequal but simply proportionate distances, and the vertical axis at a distance *not* simply proportionate to the other distances. In the ideal forms the faces are scalene triangles.

2. PYRAMID OF SECOND ORDER. — $a : \infty a : mc$; $\{h0l\}$.

Eight faces, Fig. 84, each parallel to one horizontal axis, and cutting the other and the vertical axis at distances not simple multiples of each other. In ideal forms the faces are isosceles triangles.

3. PYRAMID OF FIRST ORDER. — $a : a : mc$; $\{hhl\}$.

Eight faces, Fig. 83, each cutting the horizontal axes at equal distances, and the vertical axis at a distance *not a simple multiple*

of the basal intercepts. In ideal forms the faces are isosceles triangles.

Although there is an arbitrary choice of axes which determines the order of the pyramid, yet a first order unit $a : a : c$ {111} has not the same angles as a second order unit $a : \infty a : c$ {101}. For instance Figs. 83 and 84 represent these for the mineral scheelite and Fig. 85 shows the same forms combined, but the supplement angle $pp' = 79° 55\frac{1}{2}'$ whereas $dd' = 72° 40\frac{1}{2}'$.

FIG. 83.

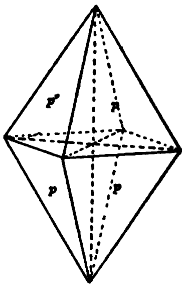


FIG. 84.

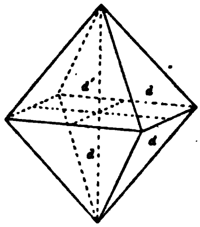
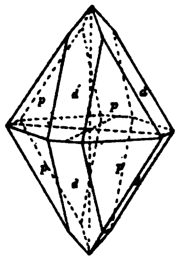


FIG. 85.



4. BASAL PINACOID. — $\infty a : \infty a : c$; {001}.

Two faces, each parallel to both the horizontal axes. The faces c of Figs. 86 to 88.

FIG. 86.

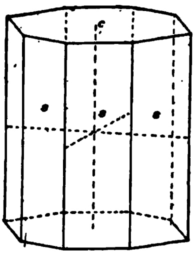


FIG. 87.

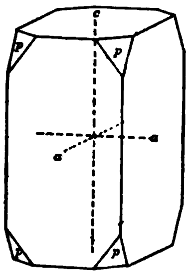
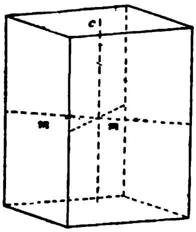


FIG. 88.



5. DITETRAGONAL PRISM. — $a : na : \infty c$; {$hk0$}.

Eight faces, each parallel to the vertical axis and cutting the two basal axes in distances unequal but simply proportionate. The faces s, Fig. 86.

The adjacent interfacial angles can not be equal, for then the symbol would be $a : 2.4142\ a : \infty c$ which is opposed to the law of rational intercepts (Cotangent 22° 30′ = 2.414213).

6. PRISM OF SECOND ORDER. — $a : \infty a : \infty c$; {100}.

Four faces each parallel to the vertical axis and to one basal axis. The interfacial angles are 90°. The faces a, Figs. 87, 90, 94, etc.

7. PRISM OF FIRST ORDER.—$a : a : \infty c$; $\{110\}$.

Four faces, each parallel to the vertical axis and cutting the basal axes at equal distances from the center. The interfacial angles are 90°. The faces *m*, Figs. 88, 89, 90, etc.

Series and Combinations in the Class of Ditetragonal Pyramid.

By considering the forms of each substance separately, a clear idea is obtained as to the pyramidal forms, which vary in shape and angle with the relative lengths of *mc* and *a*, although as ex-

FIG. 89.

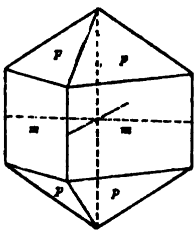


FIG. 90.

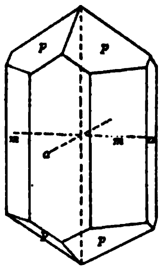


FIG. 91.

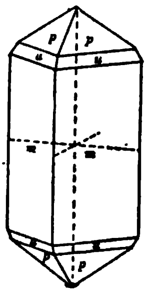
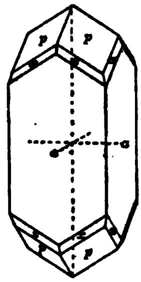


FIG. 92.



plained, p. 36, the pyramids which occur upon crystals of *any one substance* are definitely related in axial intercepts and usually very limited in number.

Zircon.—Axes $a : c = 1 : 0.640$.

Fig. 89 shows the common association of unit pyramid *p* and unit prism *m*. In Fig. 90 these two forms are combined with the prism of the second order *a* and in Fig. 91 with the pyramid $u = (a : a : 3c)$; $\{331\}$. Fig. 92 shows the union of second order prism, unit pyramid and ditetragonal pyramid $x = (a : 3a : 3c)$; $\{311\}$.

FIG. 93.

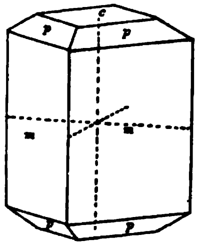


FIG. 94.

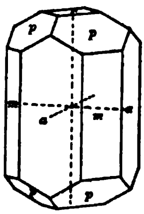
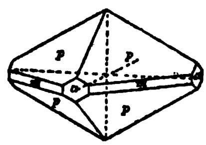


FIG. 95.



Vesuvianite.—Axes $a : c = 1 : 0.537$.

The unit pyramid in vesuvianite is only a little flatter than in zircon, hence there is little difference between the pyramid angles

in Fig. 89 and Fig. 95. The relative development of faces, or "crystal habit," is, however, markedly different.

Fig. 93 shows the combination of unit pyramid p, unit prism m and basal pinacoid c, Fig. 94 shows these three forms combined with the prism of the second order a and Fig. 95 shows the two prisms and the unit pyramid.

FIG. 96.

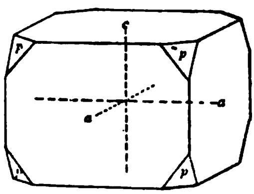


FIG. 97.

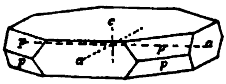


FIG. 98.

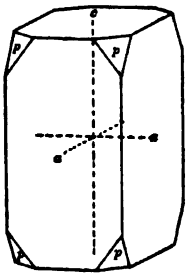
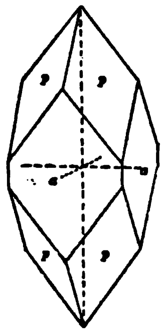


FIG. 99.



Apophyllite.—Axes $a : c = 1 : 1.252$.

As indicated by the ratios of a to c the unit pyramid of this mineral is much more acute than in zircon and vesuvianite, this is clearly apparent in Fig. 99. The figures also illustrate well the possibility of great differences in habit without any difference in occurring forms, thus Figs. 96, 97 and 98 are all combinations

FIG. 100.

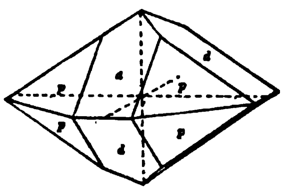
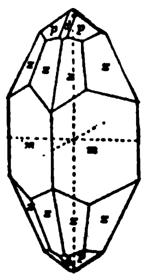


FIG. 101.



the unit pyramid p, basal pinacoid c and second order prism a. In Fig. 99 the basal pinacoid does not occur.

Cassiterite.—Axes $a : c = 1 : 0.6723$.

In this the ratio of a to c is closely as in zircon but the common

association is now the unit pyramid p with the second order pyramid d as shown in Fig. 100.

In Fig. 101 these forms occur with a ditetragonal pyramid $z = (a : \frac{3}{2} a : 3c)$ $\{321\}$ and the unit prism m.

OTHER CLASSES OF SYMMETRY IN THE TETRAGONAL SYSTEM.

Six other classes of symmetry have been distinguished in the Tetragonal system:

9. Class of the Third Order Bisphenoid. — With one axis of two-fold symmetry. No examples are known.

10. Class of the Tetragonal Pyramid of Third Order. — With one axis of four-fold symmetry. Example — Wulfenite.

11. Scalenohedral Class. — With two planes of symmetry at 90° intersecting in an axis of four-fold symmetry. Also two axes of two-fold symmetry midway between the planes. Examples — Chalcopyrite and stannite.

12. Trapezohedral Class. — Without planes of symmetry, but with one four-fold axis at 90° to four two-fold axes. No examples among minerals are known, the type salt is nickel sulphate, $NiSO_4 \cdot 6H_2O$.

13. Class of the Tetragonal Pyramid of Third Order. — With one horizontal plane of symmetry and one vertical axis of four-fold symmetry. Examples — Scheelite, wernerite and stolzite.

14. Class of the Ditetragonal Pyramid. — With four planes of symmetry intersecting in an axis of four-fold symmetry. No examples among minerals are known. An example in salts is Iodosuccinimid, $C_4H_4O_2NI$.

CHAPTER VI.

HEXAGONAL SYSTEM.*

ALL hexagonal crystals are conveniently referred to *four* crystallographic axes, one vertical and at right angles to the others, three horizontal and interchangeable and at sixty degrees to each other.

Twelve classes of symmetry are recognized which fall naturally in two divisions:

The Rhombohedral Division,† including seven classes, each with an axis of three-fold symmetry.

The Hexagonal Division, including five classes, each with an axis of six-fold symmetry.

RHOMBOHEDRAL DIVISION, SCALENOHEDRAL CLASS.

No. 13. Rhombohedral Hemihedry, *Liebisch*. No. 19. Rhombohedral Group, *Dana*.

This most important group in the hexagonal system includes the crystals of such minerals as calcite, corundum, hematite and chabazite. All crystals in the class are symmetrical to three planes

FIG. 102.

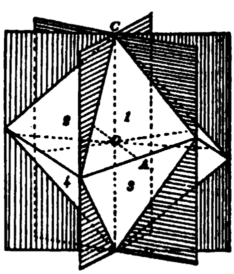


FIG. 103.

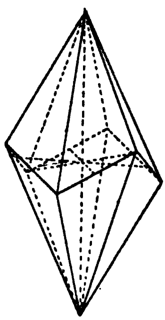
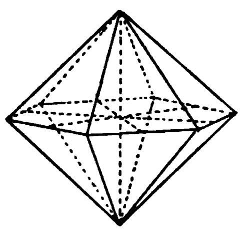


FIG. 104.



at 60° to each other, Fig. 102. Their intersection is the three-fold axis and there are three two-fold axes OA diagonal to the planes.

* Also called Rhombohedral, Sechsgliedrige, Drei-und-Einaxige and Monotrimetric.

† The "rhombohedral division" is referred by Miller to three oblique axes.

Choosing Crystallographic Axes.

The axes of symmetry are chosen. The three-fold axis is the vertical, *c*, the others are horizontal and one of them is placed from left to right.

Tabulation of the Seven Type Forms.

NAME.	FACES.	WEISS.	MILLER.
Each face oblique to *c*.			
1. SCALENOHEDRON.	12	$a : na : pa : mc$	$\{hk\bar{i}l\}$
2. HEXAG. PYRAMID 2° ORDER.	12	$2a : 2a : a : mc$	$\{h \cdot h \cdot 2\bar{h} \cdot l\}$
3. RHOMBOHEDRON 1° ORDER.	6	$a : \infty a : a : mc$	$\{\bar{h}0hl\}$
Each face perpendicular to *c*.			
4. BASAL PINACOID.	2	$\infty a : \infty a : \infty a : c$	$\{0001\}$
Each face parallel to *c*.			
5. DIHEXAGONAL PRISM.	12	$a : na : pa : \infty c$	$\{hk\bar{i}0\}$
6. HEXAG. PRISM 2° ORDER.	6	$2a : 2a : a : \infty c$	$\{11\bar{2}0\}$
7. HEXAG. PRISM 1° ORDER.	6	$a : \infty a : a : \infty c$	$\{10\bar{1}0\}$

Description of the Type Forms.

1. SCALENOHEDRON.—$a : na : pa$* $: mc$; $\{hk\bar{i}l\}$.

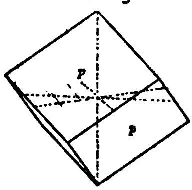
Twelve faces, each cutting all the axes. In the ideal form the faces are scalene triangles. The adjacent polar edges are necessarily unequal.

Fig. 103. Also the faces *v*, Figs. 113 and 116.

2. HEXAGONAL PYRAMID OF SECOND ORDER.—$2a : 2a : a : mc$; $\{h \cdot h \cdot 2\bar{h} \cdot i\}$.

Twelve faces, Fig. 104, each cutting one horizontal axis at a certain distance, the others at *twice* † that distance, and the vertical axis at some distance *not* simply proportionate to the rest. In the ideal form the faces are isosceles triangles.

FIG. 105.



3. RHOMBOHEDRON OF FIRST ORDER. — $a : \infty a : a : mc$; $\{h0\bar{h}i\}$.

Six faces, each cutting two basal axes at equal distances, parallel to the third and cutting the vertical. In the ideal forms the faces are rhombs, Figs. 105, 109, 110 and 114.

4. BASAL PINACOID.—$\infty a : \infty a : \infty a : c$; $\{0001\}$.

Two faces each parallel to the three horizontal axes. The faces *c* of Figs. 106 to 108.

* It may be shown that in the Weiss symbols the numerical value of $p = n / n - 1$ and in the Miller symbols that $i = -(h + k)$.

† Easily shown by the angles in a horizontal section.

5. Dihexagonal Prism.—$a : na : pa : \infty c$; $\{hk\bar{i}0\}$.

Twelve faces each parallel to the vertical axis and cutting all horizontal axes at unequal distances, simple multiples of each other, Fig. 106, shows $s = (a : \frac{3}{2}a : 3a : \infty c)$; $\{21\bar{3}0\}$.

6. Hexagonal Prism of Second Order.—$2a : 2a : a : \infty c$; $\{11\bar{2}0\}$.

Six faces each parallel the vertical axis and cutting one horizontal

Fig. 106.

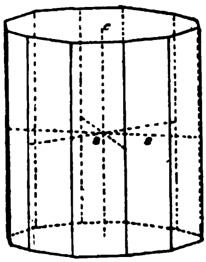


Fig. 107.

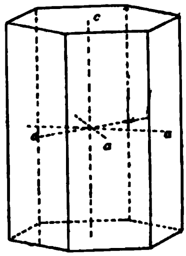
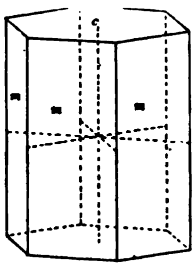


Fig. 108.



axis at a certain distance, the other two at *twice* that distance. The faces a, Figs. 107 and 121.

7. Hexagonal Prism of First Order.—$a : \infty a : a : \infty c$; $\{10\bar{1}0\}$.

Six faces each parallel to the vertical and one horizontal axis and cutting the other two at equal distances. The faces m, Figs. 108, 112 and 115.

Combinations in the Scalenohedral Class.

Calcite.—Axes $a : c = 1 : 0.854$.

Figs. 109 to 116 represent the more common of the extremely numerous forms of calcite. Rhombohedrons and scalenohedrons predominate. The rhombohedrons shown are p the unit, Fig. 109, e the negative form of $a : \infty a : a : \frac{1}{2}c$; $\{10\bar{1}2\}$; Fig. 110; f the negative form of $a : \infty a : a : 2c$; $\{20\bar{2}1\}$, Fig. 114; and q the positive form of $a : \infty a : a : 16c$; $\{16.0.\overline{16}.1\}$; Fig. 111.

Two scalenohedrons only are shown, $v = (\frac{3}{2}a : 3a : a : 3c)$; $\{21\bar{3}1\}$; Fig. 113, and $w = (\frac{4}{3}a : 4a : a : \frac{4}{5}c)$; $\{31\bar{4}5\}$; Fig. 116.

The rhombohedron e occurs more frequently than the unit and is shown in combination with the rhombohedron q in Fig. 111 and with the prism m in Figs. 112 and 115.

The unit rhombohedron is shown in combination with the scalenohedron v in Fig. 113, and with the two scalenohedrons v and w in Fig. 116.

FIG. 109.

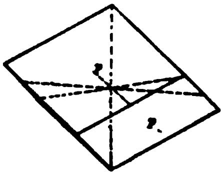


FIG. 110.

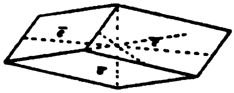


FIG. 111.

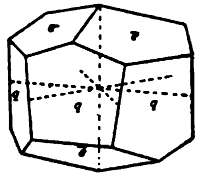


FIG. 112.

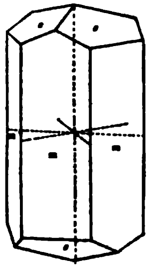


FIG. 113.

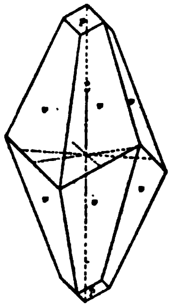
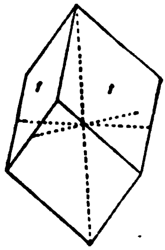


FIG. 114.



Hematite. — Axes $a : c = 1 : 1.365$.

Fig. 117 shows the unit rhombohedron p with the basal pinacoid c and the second order pyramid $n = (2a : \dot{2}a : a : \frac{4}{3}c)$; $\{22\bar{4}3\}$;

FIG. 115.

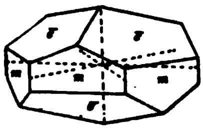


FIG. 116.

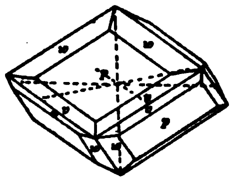


Fig. 119 shows the same except that the basal pinacoid is replaced by the rhombohedron $g = (a : \infty a : a : \frac{1}{4}c)$; $\{10\bar{1}4\}$; and Fig. 118 shows the two rhombohedrons p and g.

FIG. 117.

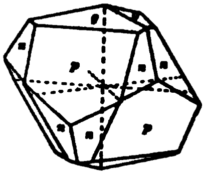


FIG. 118.

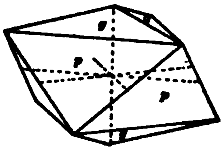
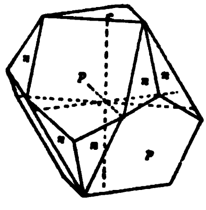


FIG. 119.



Corundum. — Axes $a : c = 1 : 1.363$.

The unit forms of hematite and corundum are practically identical,

but the combinations and habit are very different. Fig. 120 shows a second order pyramid $n = (2a : 2a : a : \frac{4}{3}c)$; $\{22\bar{4}3\}$. Fig. 121 shows this and two other second order forms $o = (2a : 2a : a : \frac{8}{3}c)$; $\{4483\}$; and $a = (2a : 2a : a : \infty c)$; $\{1120\}$; and a rhombohedron $f = (a : \infty a : a : 2c)$; $\{2021\}$. Fig. 122 shows a second order pyramid $w = (2a : 2a : a : 2c)$; $\{1121\}$; with the unit rhombohedron p and the basal pinacoid c.

FIG. 120.

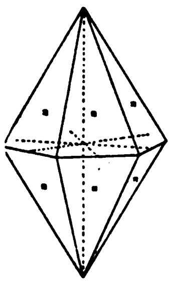


FIG. 121.

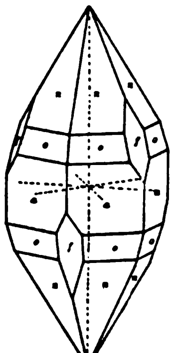
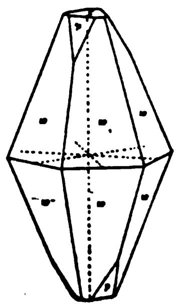


FIG. 122.



RHOMBOHEDRAL DIVISION, HEMIMORPHIC CLASS.* 20.

No. 14. Second Hemimorphic Tetartohedry, *Liebisch*. No. 20. Rhombohedral Hemimorphic Group, *Dana*.

The common mineral, tourmaline, and the ruby silvers, proustite and pyrargyrite, occur in forms showing different groupings of

FIG. 123.

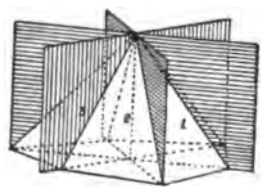
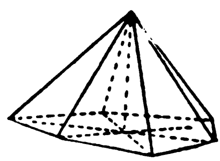


FIG. 124.



faces at opposite ends of the vertical axis. That is the forms are symmetrical to a three-fold axis and to three planes through this at 60° to each other, Fig. 123.

Choosing Crystallographic Axes.

The three-fold axis is taken as the vertical (c) axis, the others lie in the planes of symmetry.

* The forms differ so markedly from those of the preceding and following class that it has been thought wise to describe them in detail.

Tabulation of Seven Type Forms.

Name.	Faces.	Weiss.	Miller.
Each face oblique to c.			
1. Hem. Ditrigonal Pyramid.	6	$a : na : pa : mc$	$\{hk\bar{i}l\}$
2. Hem. Hex. Pyram. Second Order.	3	$2a : 2a : a : mc$	$\{h\,h{\cdot}\bar{2h}{\cdot}l\}$
3. Hem. Trigonal Pyram. First Order.	3	$a : \infty a : a : mc$	$\{h0\bar{h}l\}$
Each face perpendicular to $\dot{c}$.			
4. Basal Plane.	1	$\infty a : \infty a : \infty a : c$	$\{0001\}$
Each face parallel to $\dot{c}$.			
5. Ditrigonal Prism.	6	$a : na : pa : \infty c$	$\{hk\bar{i}0\}$
6. Hexag. Prism Second Order.	6	$2a : 2a : a : \infty c$	$\{11\bar{2}0\}$
7. Trigonal Prism First Order.	3	$a : \infty a : a : \infty c$	$\{10\bar{1}0\}$

Description of the Type Forms.

1. Hemimorph. Ditrigonal Pyramid.—$a : na : pa : mc$; $\{hk\bar{i}l\}$. Six faces, Fig. 124, each cutting all horizontal axes at simply related distances and all cutting the vertical axis.

2. Hemimorph. Hexag. Pyramid 2° Order.—$2a : 2a : a : mc$; $\{h \cdot h \cdot \bar{2h} \cdot l\}$.

Six faces, Fig. 125, each cutting one horizontal axis at a certain distance, the others at *twice* that distance, and the vertical axis at a distance *not* simply proportionate.

Fig. 125.

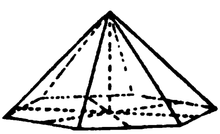
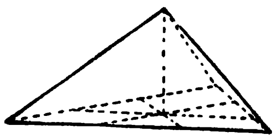


Fig. 126.



3. Hemimorph. Trigonal Pyramid 1° Order.—$a : \infty a : a : mc$; $\{h0\bar{h}l\}$.

Three faces, Fig. 126, each parallel to one horizontal axis, cutting the other two at equal distances, and the vertical axis at some distance *not* simply proportionate.

4. The Basal Plane.—$\infty a : \infty a : \infty a : c$; $\{0001\}$.

One face parallel to the basal axes.

5. Ditrigonal Prism.—$a : na : pa : \infty c$; $\{hk\bar{i}0\}$.

Six faces, Fig. 127, each parallel to the vertical axis and cutting all horizontal axes at unequal distances simple multiples of each other.

6. Hex. Prism of Second Order.—$2a : 2a : a : \infty c$; $\{h \cdot h \cdot \bar{2h} \cdot 0\}$.

Previously described. See Fig. 107.

7. Trigonal Prism of First Order.—$a : \infty a : a : \infty c$; $\{10\bar{1}0\}$.

Three vertical faces, each parallel to one horizontal axis and intersecting the others at equal distances from the center, Fig. 128.

FIG. 127.

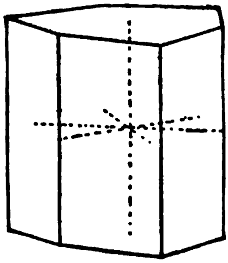
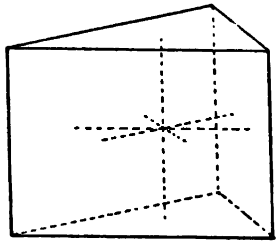


FIG. 128.



Combinations in the Hemimorphic Class.

Tourmaline.—Axes $a : c = 1 : 0.447$.

Fig. 129 shows the first order trigonal prism m, the second order hexagonal prism a; at the upper end the trigonal pyramids of first order $p = (a : \infty a : a : c)$; $\{10\bar{1}1\}$; and $f = (a : \infty a : a : 2c)$: $\{20\bar{2}1\}$; but at the lower end the trigonal pyramid p only. Fig. 130 shows m, p and a, but does not so evidently reveal the hemimorphic symmetry. Fig. 131 again shows m and a central, with at one end p and at the other f.

FIG. 129.

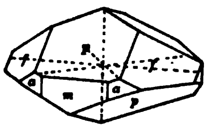


FIG. 130.

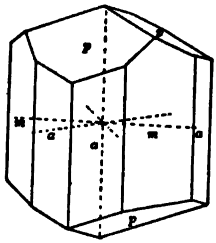
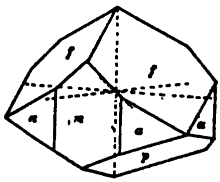


FIG. 131.



OTHER CLASSES OF SYMMETRY IN THE RHOMBOHEDRAL DIVISION.

In each there is an axis of three-fold symmetry.

16. CLASS OF HEMIMORPH. TRIGONAL PYRAMID 3° ORDER.

The three-fold axis No planes or center of symmetry. Example sodium periodate, $NaIO_4 \cdot 3H_2O$.

17. CLASS OF RHOMBOHEDRON 3° ORDER.

The three-fold axis and center of symmetry. Examples—Dolomite, ilmenite, willemite, phenacite, dioptase.

18. CLASS OF TRIGONAL TRAPEZOHEDRON.

The three-fold axis and three two-fold axes of symmetry at 90° thereto. Examples — Quartz, cinnabar.

19. CLASS OF TRIGONAL PYRAMID 3° ORDER.

The three-fold axis and one plane of symmetry at 90° thereto. No examples known.

22. CLASS OF DITRIGONAL PYRAMID.

The three-fold axis, three planes at 60° and one at 90° to the three. No examples known.

HEXAGONAL DIVISION. CLASS OF DIHEXAGONAL PYRAMID. 27.

No. 6. Holohedral, *Liebisch*. No. 13. Normal Group, *Dana*.

A few minerals, notably beryl, crystallize in forms symmetrical to one horizontal plane and to six vertical planes at thirty degrees to each other and to one six-fold and six two-fold axes which are the lines of intersection of these planes, Fig. 132.

Choosing Crystallographic Axes.

The six-fold axis is chosen as the vertical c, the two-fold axes as the horizontal axes a, one of which is conventionally placed from left to right.

Tabulation of the Seven Type Forms.

NAME.	FACES.	WEISS.	MILLER.
Each face oblique to $\dot{c}$.			
1. DIHEXAGONAL PYRAMID.	24	$a : na : pa : mc$	$\{hkil\}$
2. HEXAG. PYRAMID 2° ORDER.	12	$2a : 2a : a : mc$	$\{h{\cdot}h\,\overline{2h}{\cdot}l\}$
3. HEXAG. PYRAMID 1° ORDER.	12	$a : \infty a : a : mc$	$\{h0\bar{h}l\}$
Each face perpendicular to $\dot{c}$.			
4. BASAL PINACOID.	2	$\infty a : \infty a : \infty a : c$	$\{0001\}$
Each face parallel to $\dot{c}$.			
5. DIHEXAGONAL PRISM.	12	$a : na : pa : \infty c$	$\{hki0\}$
6. HEXAG. PRISM 2° ORDER.	6	$2a : 2a : a : \infty c$	$\{11\bar{2}0\}$
7. HEXAG. PRISM 1° ORDER.	6	$a : \infty a : a : \infty c$	$\{10\bar{1}0\}$

Description of the Type Forms.

1. DIHEXAGONAL PYRAMID.—$a : na : pa : mc$; $\{hkil\}$.

Twenty-four faces, Fig. 133, each of which cuts the three horizontal axes at unequal distances, simple multiples of each other; and the vertical axis at some distance *not* simply related to the others. In the ideal form the faces are scalene triangles.

2. HEXAGONAL PYRAMID OF SECOND ORDER.—See Fig. 104.

3. HEXAGONAL PYRAMID OF FIRST ORDER.—$a : \infty a : a : mc$; $\{h0\bar{h}l\}$.

Twelve faces, Fig. 134, each parallel to one horizontal axis, cutting the others at equal distances, and the vertical axis at some distance *not* simple proportionate. In ideal forms the faces are isosceles triangles.

4. BASAL PINACOID.—The faces c of Figs. 135 to 137.

5. DIHEXAGONAL PRISM.—See Fig. 106.

FIG. 132.

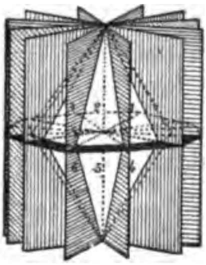


FIG. 133.

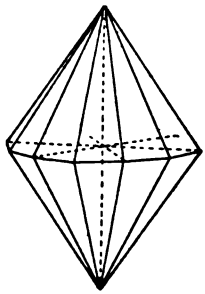
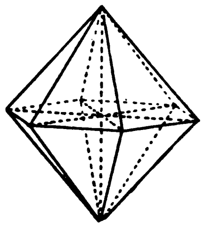


FIG. 134.



6. HEXAGONAL PRISM OF SECOND ORDER.—See Fig. 107.

7. HEXAGONAL PRISM OF FIRST ORDER.—See Fig. 108 or the faces m of Figs. 135 to 137.

Combinations in the Class of Dihexagonal Pyramid.

Beryl.—Axes $a : c = 1 : 0.499$.

FIG. 135.

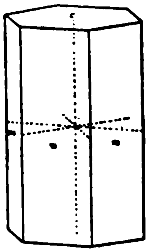


FIG. 136.

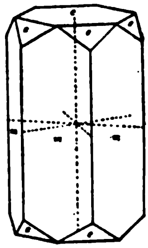


FIG. 137.

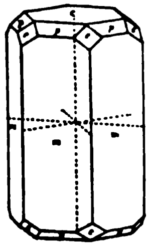


Fig. 135 shows the prism of first order m and basal pinacoid c; in Fig. 136 the second order pyramid $c = (2a : 2a : a : 2c)$; $\{11\bar{2}1\}$; occurs and in Fig. 137 the unit pyramid p is also present.

OTHER CLASSES IN THE HEXAGONAL DIVISION.

Each with an axis of six-fold symmetry.

23. Class of Third Order Hexagonal Pyramid. — The six-fold axis only. Example—nephelite.

24. Class of Hexagonal Trapezohedron. — The six-fold axis and six 2-fold axes of symmetry at 90° thereto. Example — Barium-antimonyl dextro-tartrate potassium nitrate, $Ba(SbO)_2$-$(C_4H_4O_6)_2 \cdot KNO_3$.

25. Class of Third Order Hexagonal Pyramid. — The six-fold axis and a plane of symmetry at 90° thereto. Examples — Apatite, pyromorphite, mimetite, vanadinite.

26. Class of Hemimorphic Dihexagonal Pyramid. — The six-fold axis and six planes of symmetry at 30° to each other intersecting therein. Example — Iodyrite.

CHAPTER VII.

ISOMETRIC SYSTEM.

THE Isometric* system includes all crystal forms which can be referred to three interchangeable axes at right angles to each other, that is axes about which there are equal numbers of faces grouped with corresponding faces at the same angles.

Five classes are distinguished, of which three include nearly all known isometric minerals.

HEXOCTAHEDRAL CLASS. 32.

No. 1. Holohedral, *Liebisch*. No. 1. Normal Group, *Dana*.

Symmetry of the Class.

There are three planes of symmetry, Fig. 138, parallel to cube faces, and six planes through diagonally opposite cube edges. There are also, Fig. 139, three four-fold, four three-fold and six two-fold axes of symmetry.

Choosing Crystallographic Axes.

The three axes of four-fold symmetry are chosen as the crystallographic axes. Usually one is assumed to be vertical and one to extend from left to right.

Tabulation of the Seven Type Forms.

NAME.	FACES.	WEISS.	MILLER.
Each face intersects all axes.			
1. HEXOCTAHEDRON.	48	$a : na : ma$	$\{hkl\}$
2. TRAPEZOHEDRON.	24	$a : ma : ma$	$\{hkk\}$
3. TRISOCTAHEDRON.	24	$a : a : ma$	$\{hhl\}$
4. OCTAHEDRON.	8	$a : a : a$	$\{111\}$
Each face parallel to one axis.			
5. DODECAHEDRON.	12	$a : a : \infty a$	$\{110\}$
6. TETRAHEXAHEDRON.	24	$a : na : \infty a$	$\{hk0\}$
Each face parallel to two axes.			
7. CUBE.	6	$a : \infty a : \infty a$	$\{100\}$

Description of the Type Forms.

1. HEXOCTAHEDRON.—$a : na : ma$; $\{hkl\}$.

* Also called Tesseral, Tessular, Regular, Cubic and Monometric.

Forty-eight faces each cutting the three axes in three different, but simply proportionate distances. In the ideal forms the faces are scalene triangles. Fig. 140 shows $a : \frac{3}{2}a : 3a$; $\{321\}$.

FIG. 138.

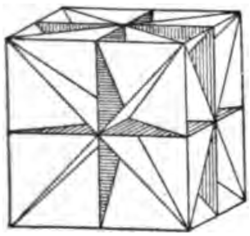
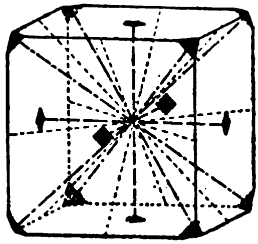


FIG. 139.



The small black squares and triangles indicate axes of four-fold and three-fold symmetry respectively.

2. TRAPEZOHEDRON. — $a : ma : ma$; $\{hkk\}$.

Twenty-four faces, each cutting two axes equally and the third in some shorter distance bearing a simple ratio to the others. In

FIG. 140.

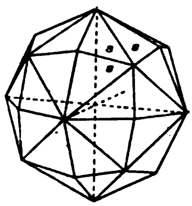


FIG. 141.

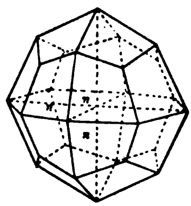
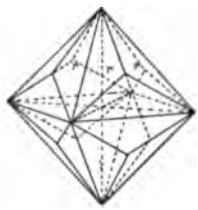


FIG. 142.

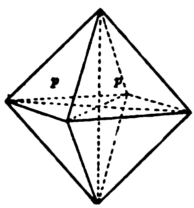


the ideal form the faces are trapeziums. Fig. 141 shows $a : 2a : 2a$; $\{211\}$.

3. TRISOCTAHEDRON. — $a : a : ma$; $\{hhl\}$.

Twenty-four faces, each cutting two axes at equal distances, the third axes at some longer distance a simple multiple of the others. In the ideal forms the faces are isosceles triangles. Fig. 142 shows $r = (a : a : 2a)$; $\{221\}$.

FIG. 143.



4. THE OCTAHEDRON. — $a : a : a$; $\{111\}$.

Eight faces, Fig. 143, each cutting the three axes at equal distances. In the ideal form the faces are equilateral triangles.

5. TETRAHEXAHEDRON. — $a : na : \infty a$; $\{hk0\}$.

Twenty-four faces, Fig. 144, each parallel to one axis and cut-

ting the other two unequally in distances bearing a simple ratio to each other. In the ideal forms the faces are equal isosceles triangles. Fig. 144 shows $a : 2a : \infty a$; $\{210\}$.

FIG. 144.

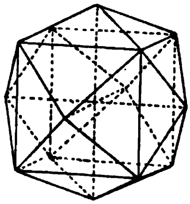


FIG. 145.

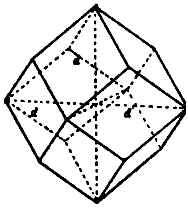
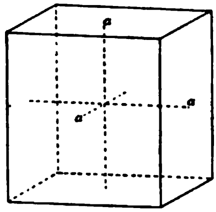


FIG. 146.



6. THE DODECAHEDRON. — $a : a : \infty a$; $\{110\}$.

Twelve faces, Fig. 145, each parallel to one axis and cutting the others at equal distances. In the ideal form each face is a rhombus.

7. THE CUBE. — $a : \infty a : \infty a$; $\{100\}$.

FIG. 147.

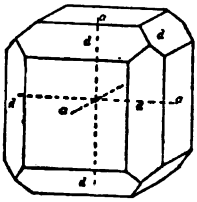


FIG. 148.

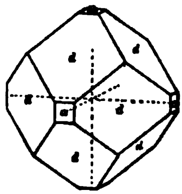
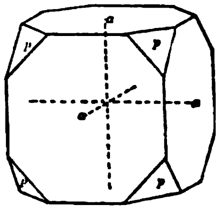


FIG. 149.



Six faces, Fig. 146, each parallel to two axes. In the ideal forms the faces are squares.

Combinations in the Hexoctahedral Class.

The most frequently occurring forms are the cube *a*, the octahe-

FIG. 150.

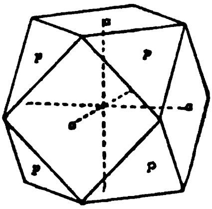


FIG. 151.

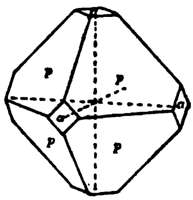
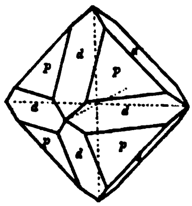


FIG. 152.



dron *p*, the dodecahedron *d*, and the trapezohedron $n = (a : 2a : 2a)$; $\{211\}$. The other forms usually occur modifying these.

The cube *a* and dodecahedron *d*, Figs. 147, 148, are combined in crystals of fluorite, argentite and cuprite. The cube and octa-

hedron p, Figs. 149, 150 and 151, are very frequently combined in fluorite, galenite, silver, sylvite and many other minerals. The octahedron, p, and dodecahedron, d, Figs. 152 and 153, are frequently found in spinel, magnetite, franklinite and cuprite, while

FIG. 153.

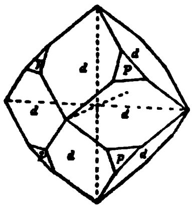


FIG. 154.

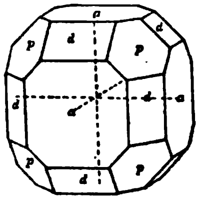
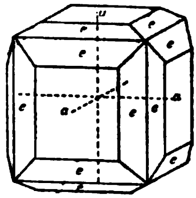


FIG. 155.



the three together, cube, dodecahedron and octahedron, Fig. 154, occur in smaltite, galenite and fluorite. The tetrahexahedron $e = (a : 2a : \infty a)$; $\{210\}$; is found with the cube in fluorite, Fig. 155.

FIG. 156.

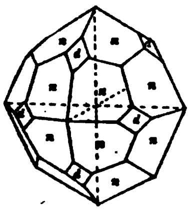


FIG. 157.

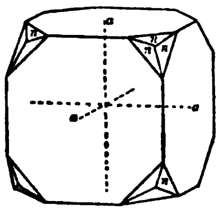
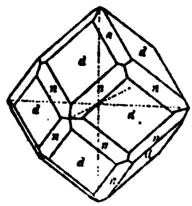


FIG. 158.



The trapezohedron $n = (a : 2a : 2a)$; $\{211\}$; is common in analcite, garnet and amalgam, either combined with the dodecahedron, Figs. 156 and 158 or with the cube, Fig. 157.

FIG. 159.

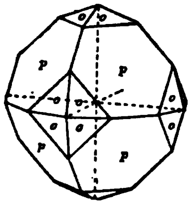


FIG. 160.

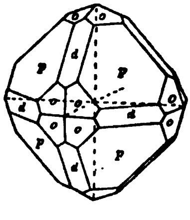
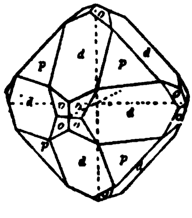


FIG. 161.



Another trapezohedron $o = (a : 3a : 3a)$; $\{311\}$; occurs in spinel and magnetite either with the octahedron, Fig. 159, or with both octahedron and dodecahedron, Figs. 160 and 161.

The trisoctahedron $r = (a : a : 2a)$; $\{221\}$; occasionally occurs, especially in galenite and magnetite, combined with octahedron

and dodecahedron, Fig. 162. The hexoctahedron $t = (a : 2a : 4a)$; $\{421\}$; occurs modifying cubes of fluorite, Fig. 163, and another hexoctahedron $s = (a : \frac{3}{2}a : 3a)$; $\{321\}$; occurs in garnet, Fig. 164.

FIG. 162.

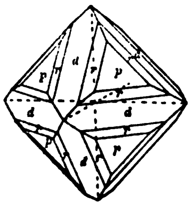


FIG. 163.

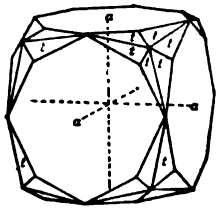
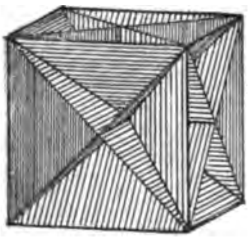


FIG. 164.

HEXTETRAHEDRAL CLASS. 31.

No. 2. Tetrahedral Hemihedry, *Liebisch*. No. 3. Tetrahedral Group, *Dana*.

FIG. 165.



In this class of isometric forms, to which crystals of the diamond, tetrahedrite, sphalerite and boracite belong, the shaded planes of Fig. 138 are no longer planes of symmetry, and the symmetry is restricted to the diagonal planes shown in Fig. 165 and to the four three-fold and three two-fold axes formed by their intersection.

Choosing Crystallographic Axes.

The three axes of two-fold symmetry are chosen as the crystallographic axes.

Tabulation of the Seven Type Forms.

NAME.	FACES.	WEISS.	MILLER.
Each face intersects all axes.			
1. HEXTETRAHEDRON.	24	$a : na : ma$	$\{hkl\}$
2. TRISTETRAHEDRON.	12	$a : ma : ma$	$\{hkk\}$
3. DELTOHEDRON.	12	$a : a : ma$	$\{hhl\}$
4. TETRAHEDRON.	4	$a : a : a$	$\{111\}$
Each face parallel to one axis.			
5. TETRAHEXAHEDRON.	24	$a : na : \infty a$	$\{hk0\}$
6. DODECAHEDRON.	12	$a : a : \infty a$	$\{110\}$
Each face parallel to two axes.			
7. CUBE.	6	$a : \infty a : \infty a$	$\{100\}$

Descriptions of the Type Forms.

1. HEXTETRAHEDRON.—$a : na : ma$; $\{hkl\}$.

Twenty-four faces each cutting the three axes in three different,

but simply proportionate, distances. In the ideal forms the faces are scalene triangles. Fig. 166.

2. TRISTETRAHEDRON. — $a : ma : ma$; $\{hkk\}$.

Twelve faces, Fig. 167, each cutting two axes equally and the

FIG. 166.

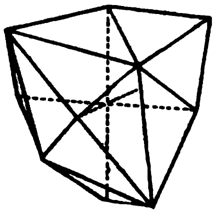
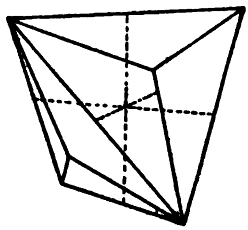


FIG. 167.



third in some shorter distance bearing a simple ratio to the others. In the ideal form the faces are isosceles triangles.

3. DELTOHEDRON. — $a : a : ma$; $\{hhl\}$.

Twelve faces, each cutting two axes equally and the third in some longer distance a simple multiple of the others. In the ideal form the faces are trapeziums. Fig. 168 shows $r = (a : a : 2a)$; $\{221\}$.

FIG. 168.

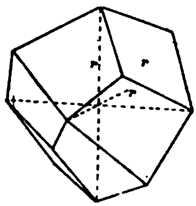
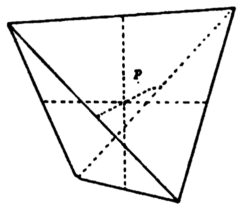


FIG. 169.



4. THE TETRAHEDRON. — $a : a : a$; $\{111\}$.

Four faces, Fig. 169, each cutting the three axes at equal distances. In the ideal form the faces are equilateral triangles.

5. TETRAHEXAHEDRON. — Fig. 144.

6. THE DODECAHEDRON. — Fig. 145.

7. THE CUBE. — Fig. 146.

Combinations in the Hextetrahedral Class.

The characteristics of the crystals of this group are best shown in combinations of forms, since the simple forms are comparatively rare and the predominating form is frequently the cube.

The combination of the positive and negative tetrahedrons, Fig. 170 occurs in crystals of sphalerite and tetrahedrite. The combi-

nation of the tetrahedron and cube *a*, Figs. 171 and 172, is common in boracite and pharmacosiderite. The tetrahedron with the dodecahedron *d*, Fig. 173, occurs in tetrahedrite, and with both cube and dodecahedron, Fig. 174, in boracite.

FIG. 170.

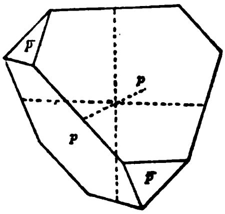


FIG. 171.

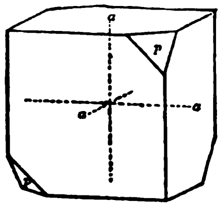
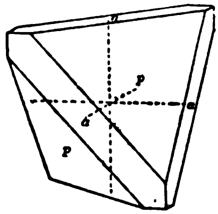


FIG. 172.



Figs. 175 and 176 are crystals of tetrahedrite. In Fig. 175 the negative form of $n = (a : 2a : 2a)$; $\{211\}$; occurs and in Fig. 176 the positive form of *n* with the dodecahedron *d*.

FIG. 173.

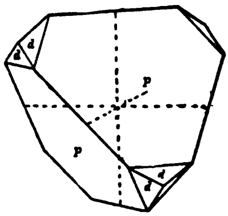


FIG. 174.

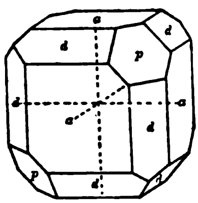


FIG. 175.

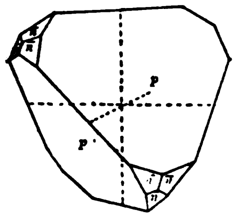


Fig. 177 includes the dodecahedron *d*, the deltohedron $r = (a : a : 2a)$; $\{221\}$; and the tristetrahedrons $o = (a : 3a : 3a)$; $\{311\}$; and $n = (a : 2a : 2a)$; $\{211\}$; Fig. 178 shows the hextetrahedron *s*

FIG. 176.

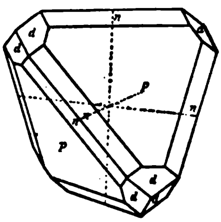


FIG. 177.

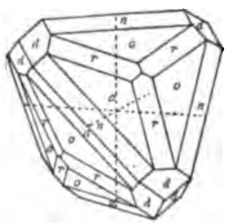
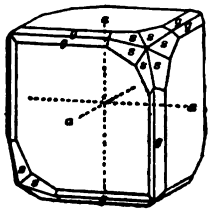


FIG. 178.



$= (a : \frac{3}{2}a : 3a)$; $\{321\}$; combined with the cube and tetrahexahedron $g = (a : \frac{3}{2}a : \infty a)$; $\{320\}$.

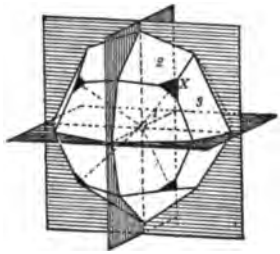
CLASS OF THE DIPLOID. 30.

No. 4. Pentagonal Hemihedry, *Liebisch*. No. 2. Pyritohedral Group, *Dana*.

Symmetry of the Class.

Crystals of the common mineral pyrite and of the minerals cobaltite and smaltite are symmetrical to three planes at right angles and to three axes of two-fold and four axes of three-fold symmetry, as shown in Fig. 179.

FIG. 179.



Choosing Crystallographic Axes.

The three axes of two-fold, symmetry are chosen as the crystallographic axes.

Tabulation of the Seven Type Forms.

NAME.	WEISS.	MILLER.
Each face intersects all the axes.		
1. DIPLOID.	$a : na : ma$	$\{hkl\}$
2. TRAPEZOHEDRON.	$a : ma : ma$	$\{hkk\}$
3. TRISOCTAHEDRON.	$a : a : ma$	$\{hhl\}$
4. OCTAHEDRON.	$a : a : a$	$\{111\}$
Each face parallel to one axis.		
5. PYRITOHEDRON.	$a : na : \infty a$	$\{hk0\}$
6. DODECAHEDRON.	$a : a : \infty a$	$\{110\}$
Each face parallel to two axes.		
7. CUBE.	$a : \infty a : \infty a$	$\{100\}$

Description of the Type Forms.

1. DIPLOID. — $a : na : ma$; $\{hkl\}$.

Twenty-four faces each cutting the three axes in three different, but simply proportionate, distances. In the ideal form the faces are trapeziums. Fig. 180 shows a positive form.

FIG. 180.

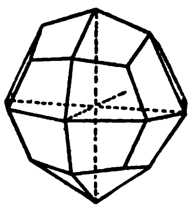
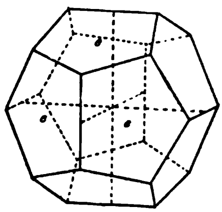


FIG. 181.



2. TRAPEZOHEDRON, Fig. 141.
3. TRISOCTAHEDRON, Fig. 142.
4. THE OCTAHEDRON, Fig. 143.

5. PYRITOHEDRON. — $a : na : \infty a$; $\{hk0\}$.

Twelve faces, Fig. 181, each parallel to one axis and cutting the other two unequally in distances bearing a simple ratio to each other. In the ideal forms the faces are pentagons.

6. THE DODECAHEDRON, Fig. 145.

7. THE CUBE, Fig. 146.

Combinations in the Class of the Diploid.

FIG. 182.

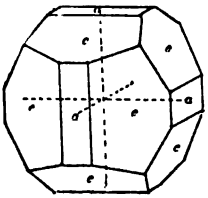


FIG. 183.

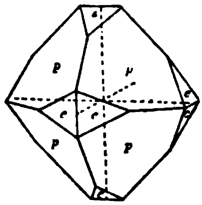


FIG. 184.

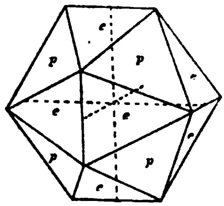


Fig. 182 shows the pyritohedron $e = (a : 2a : \infty a)$; $\{210\}$; with the cube a. Figs. 183 and 184 show the same form with the octahedron p.

FIG. 185.

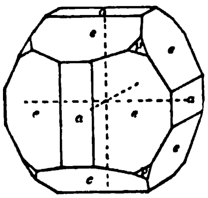


FIG. 186.

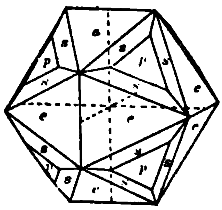


FIG. 187.

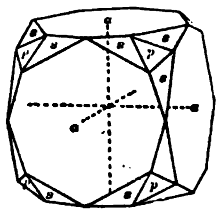


Fig. 185 shows the three forms combined. Fig. 186 shows the same pyritohedron e and octahedron p combined with the diploid $s = (a : \frac{3}{2}a : 3a)$; $\{321\}$; and Fig. 187 shows this diploid with the cube and octahedron.

OTHER CLASSES IN THE ISOMETRIC SYSTEM.

28. CLASS OF THE TETARTOID. — Three axes of two-fold symmetry at 90° to cube faces and four of three-fold through opposite corners of the cube. Example — Ullmannite.

29. CLASS OF THE GYROID. — Three axes of four-fold symmetry, at 90° to cube faces, four of three-fold through opposite corners of cube, six of two-fold through diagonally opposite edges. Examples — Sylvite, sa-lammoniac.

CHAPTER VIII.

TWIN CRYSTALS OR MACLES.

CRYSTALS frequently form which evidently consist of two individuals one of which is reversed with respect to the other. In such crystals reëntrant angles are common and familiar shapes are frequently suggested such as crosses, Fig. 188, hearts, Fig. 189, and arrow-heads, Fig. 190.

FIG. 188.

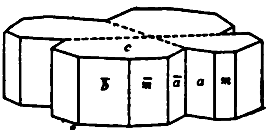


FIG. 189.

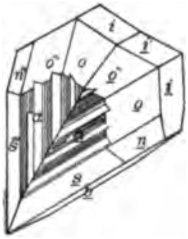
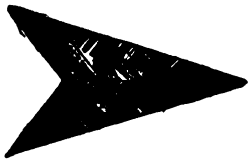


FIG. 190.



Such growths are called twin crystals or macles. When two individuals penetrate each other they constitute a *penetration twin*, and when they do not they constitute a *contact or juxtaposition twin*, the distinction between these being unimportant.

With respect to their symmetry twin crystals may be divided into:

FIG. 191.

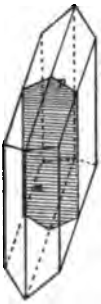


FIG. 192.

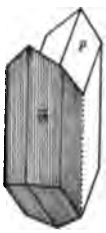
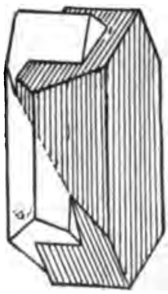


FIG. 193.



(a) Reflection Twins. — Symmetrical to a so-called "*twin plane*" which is always parallel to a possible face of the crystal but being

a plane of symmetry for the pair of crystals, cannot be a plane of symmetry for either individually. Fig. 191 shows a gypsum crystal with a shaded plane parallel to the orthopinacoid, and Fig. 192 shows the corresponding reflection twin.

(b) **Rotation Twins.** — Symmetrical to a so-called "*Twin Axis*" which is always parallel to a possible edge of the crystal but cannot be an axis of two-fold, four-fold, or six-fold symmetry, because a rotation of 180° about it would bring the crystals into an identical instead of a reversed position.

Fig. 193 shows an interpenetrating rotation twin of orthoclase, the twin axis being parallel an edge of the prism.

Repeated Twinning. (*Polysynthetic Twins, Pseudo Symmetry.*)

Frequently there is a repetition of the twinning, a third individual occurring reversed upon the second, a fourth upon the third and so on.

FIG. 194.

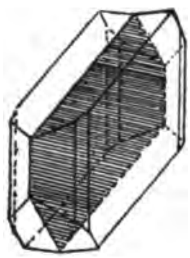
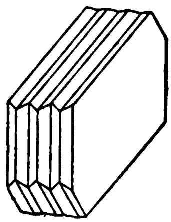


FIG. 195.



If the successive twin planes are parallel the phenomenon is called polysynthetic twinning and there often result crystals in which the individuals have been reduced to thin lamellæ and the

FIG. 196.

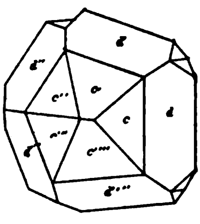


FIG. 197.

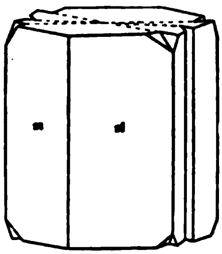
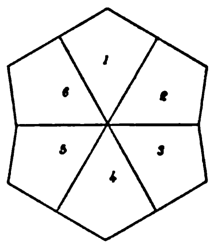


FIG. 198.



reëntrant angles to striæ. Fig. 194 shows an albite twin and Fig. 195 repeated or polysynthetic twinning of the same mineral.

If the successive twin planes are oblique to each other the regular repetition may lead to what are known as "circular forms."

For instance repeated twins of the orthorhombic marcasite with the prism face as the twin plane, lead to a circular form of five individuals, Fig. 196, because the prism angle 74° 55′ is approximately 360° ÷ 5.

Sometimes the "circular form" approximates a shape belonging to a higher class of symmetry, for instance the orthorhombic aragonite often occurs in pseudohexagonal forms, Fig. 197, due to twinning with the twin plane the prism face. As the prism angle is 63° 48′ the cross section is not a perfect hexagon as is shown, Fig. 198.

Secondary Twinning.

Twin lamellæ may be produced artificially by pressure in a number of species, the most familiar being that shown in Fig. 277. There are often found in nature twin lamellæ apparently due to pressure.

TRICLINIC TWINS.

Reflection Twins. — The brachy pinacoid is the most frequent twin plane. Fig. 199 shows a twin of albite.

FIG. 199.

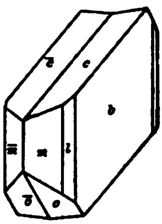
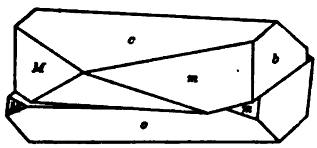


FIG. 200.



Rotation Twins. — In the so-called pericline twin of albite the macro axis is the twin axis, Fig. 200.

MONOCLINIC TWINS.

Rotation Twins. — In this system twins with a twin axis parallel to a prism edge are common.

Figs. 201 and 202 show such twins in gypsum and pyroxene and Fig. 193 shows a similar but interpenetrating twin of orthoclase.

Reflection Twins.—These also occur, as for instance in orthoclase, Fig. 203. Here again the angle is nearly an aliquot part

FIG. 201.

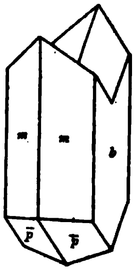


FIG. 202.

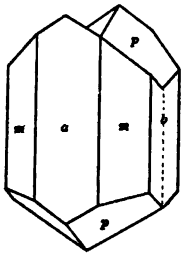
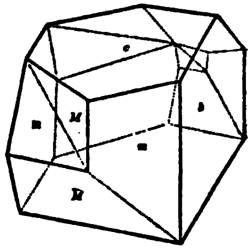


FIG. 203.



of 360, the twin plane being parallel to the face of a dome of 89° 53′.

ORTHORHOMBIC TWINS.

Reflection Twins.—The usual twin planes are faces of prisms or domes *and especially* those with angles near an aliquot part of 360° as 60° or 72° or 45° or 90°.

FIG. 204.

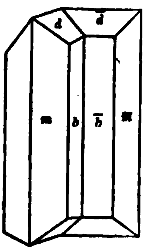


FIG. 205.

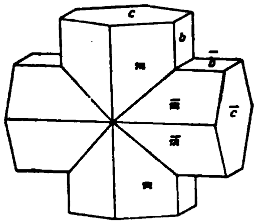
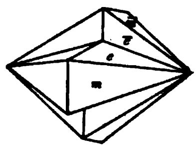


FIG. 206.



Two such have already been referred to Figs. 196 and 197. Fig. 204 shows the aragonite twin, the prism angle being 63° 48′, and Fig. 205 shows a twin of staurolite, the twin plane a brachy dome face with angle of 91° 22′, and Fig. 206 shows a twin of arsenopyrite, the twin plane a macro dome face with an angle of 59° 22′.

TETRAGONAL TWINS.

Reflection Twins with the twin plane a face of the second order pyramid are most common. Fig. 207 shows a contact twin of cassiterite and Fig. 208 a contact twin of hausmannite.

Rotation Twins. — In scheelite, Fig. 209, the twin axis is parallel to a prism edge.

FIG. 207.

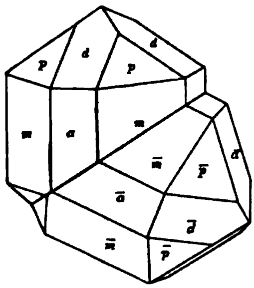


FIG. 208.

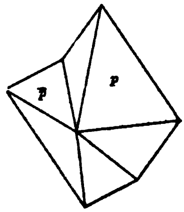
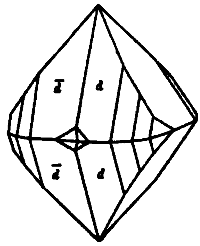


FIG. 209.



HEXAGONAL TWINS.

Twins are rare in the class of highest symmetry of this system. In the scalenohedral class twins occur with the twinning plane parallel to a rhombohedron or base but not to a prism face.

FIG. 210.

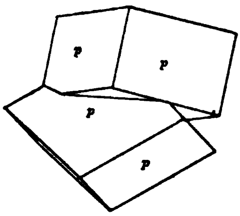
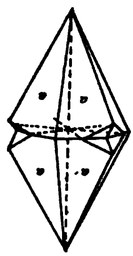


FIG. 211.



Reflection Twins of calcite are shown in Fig. 210 which represents the unit rhombohedron with the twin plane $a : \infty a : a : \frac{1}{2}c$; $\{10\bar{1}2\}$.

Fig. 211 shows a scalenohedron twin with the twin plane the basal pinacoid.

Rotation Twins. — Fig. 211 may also be regarded as a rotation twin, the twin axis parallel to a prism edge.

In quartz, twins of this kind occur like Fig. 212, but more frequently interpenetrating and as then the positive rhombohedron of one coincides with the negative of the other, the twin structure is only recognized by etching.

Fig. 213 is frequently found in quartz but is not a true twin be-

FIG. 212.

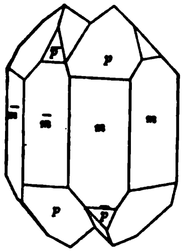
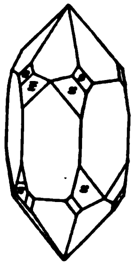


FIG. 213.



cause the individuals are one positive and the other negative. Basal sections will show characteristic optical phenomena.

FIG. 214.

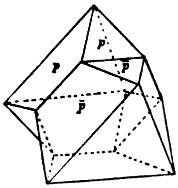


FIG. 215.

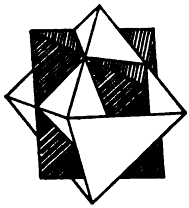
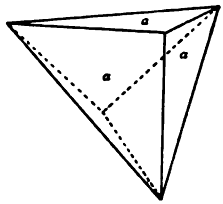


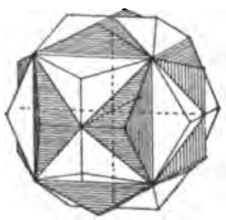
FIG. 216.



Isometric Twins.

Reflection twins are common, especially with an octahedron face as the twin plane. Fig. 214 shows a contact twin octahedron very frequent in the spinel group, and 215 the corresponding interpenetration twin, the faces of one individual shaded. Fig. 216 shows the contact twin cube.

FIG. 217.



Rotation twins occur, especially rotation about a vertical edge (cube edge). Fig. 217. shows the "Iron Cross" of pyrite which is the twin pyritohedron of this type. The faces of one individual are shaded.

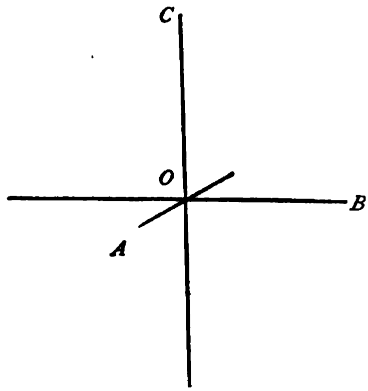
CHAPTER IX.

CRYSTAL DRAWING AND GRAPHIC SOLUTION OF STEREOGRAPHIC PROJECTIONS.

FOR description and illustration crystals are usually projected upon a vertical plane by parallel rays oblique to the plane of projection. The eye is conceived to be at an infinite distance but a little to the right and above the center of the crystal.

The figures obtained in this way have an appearance of solidity, all parallel edges are parallel in the projection and all points in a given line remain the same *proportionate* distances apart.

FIG. 218.



Construction of "Axial Cross."

A definite relation exists* between the projected lengths and angles of the isometric axes and the angles of elevation and rotation to the right, of the line of sight.

For the drawings of this book the projected isometric "axial cross" consists of three lines, Fig. 218, intersecting at a common center and with $BOC = 93° \ 8'$, $AOC = 116° \ 17'$ and $OA : OB : OC = 37 : 100 : 104$.

Tetragonal Axial Cross.

OA and OB of the isometric cross, Fig. 218, are unchanged but OC is multiplied by the value c for the particular crystal. Thus if $c = 0.64$ the half vertical axis is sixty-four one-hundredths of the length of OC.

Orthorhombic Axial Cross.

OB of the isometric "cross" is unchanged; OA is multiplied by the value of $\breve{a}$, and OC by the value of c. Thus if $\breve{a} : \bar{b} : c =$

* Moses, *Characters of Crystals*, p. 79, for other projections.

0.815 : 1 : 1.312 OB is unchanged, OA is made approximately eight tenths of its isometric length and OC is made approximately one and one third times its isometric length.

Monoclinic Axial Cross.

One axis has a different inclination to the corresponding isometric axis. To obtain this *direction* in perspective proceed as follows:

Upon the isometric "cross" lay off $Or = OC \cos \beta$ and $On = OA \sin \beta$, Fig. 219. Complete the parallelogram $OrDn$; then is DD the projection of a line equal in length to an isometric axis but in the *direction* of the desired clino axis.

OD is then multiplied by the value of $\breve{a}$ and OC by the value of c as in the orthorhombic.

FIG. 219.

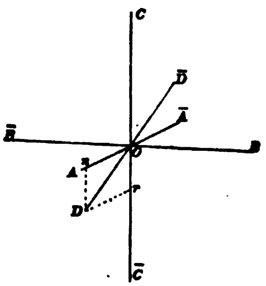
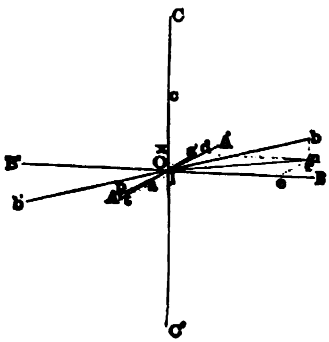


FIG. 220.



Triclinic Axial Cross.

The same method is carried further, for instance, Fig. 220: The constants for axinite are $\breve{a} : \breve{b} : c = 0.492 : 1 : 0.479$, $a \wedge c = \beta = 91^\circ\ 52'$, $b \wedge c = \alpha = 82^\circ\ 54'$, $a \wedge b = \gamma = 131^\circ\ 39'$.

Vertical Axis.— Make $Oc = OC \times .479$.

Macro Axis. — Make $Oe = OB \sin 131^\circ\ 39'$, and $Od = OA \cos 131^\circ\ 39'$; complete the parallelogram $dOen$. Make $Or = On \sin 82^\circ\ 54'$ and $Ox = OC \cos 82^\circ\ 54'$; complete the parallelogram $rOxb$. Then is Ob the projection of one half the desired axis.

Brachy Axis. — Make $Ol = OC \cos 91^\circ\ 52'$, and $Op = OA \sin 91^\circ\ 52'$. Complete the parallelogram $pOlt$; make $Oa = 0.492 \times Ot$; then is Oa the projection of one half the desired axis.

Hexagonal Axial Cross.

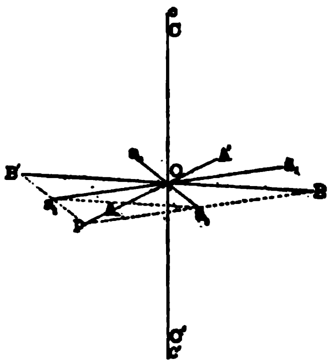
The proportionate value of c is laid off on CC' and the basal axes are derived as follows, Fig. 221:

Make $Op = OA \times 1.732$; draw pB and pB'; bisect Op by a line parallel to BB'; then are OB, Oa and Oa_3 the projections of desired semi-axes.

Determination of the Direction of Edges.

The unit form is obtained by joining the extremities of the axial cross by straight lines, and other simple forms are easily drawn by methods which suggest themselves; for instance, the unit prism by lines through the terminations of the basal axes parallel to the vertical axis. It is always possible, also, to obtain two points of any edge by actually constructing the two planes and finding the intersection of their traces in two axial planes. The method, however, is cumbersome.

FIG. 221.

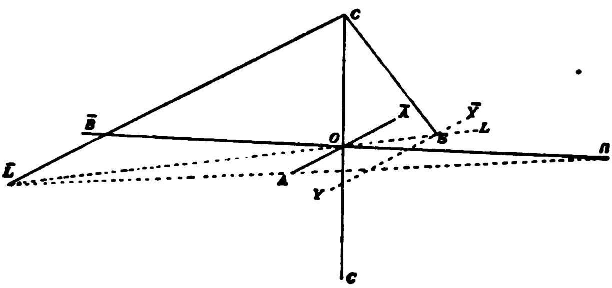


In all systems the projected intersections of *any* planes may be simply found by the following method:

(*a*) Draw the axial cross as previously directed.

(*b*) Reduce each symbol of Weiss by dividing all coefficients by the coefficient of c.

FIG. 222.



Or reduce each symbol of Miller by taking the reciprocals and dividing each term therein by the third.

(*c*) The symbols now represent each face moved parallel to itself until it cuts $\dot{c}$ at a unit's length.

Therefore any edge has one point at $\dot{c}$ and another at the inter-

section of the traces of the two faces on the plane of the basal axes.

The method will be sufficiently illustrated by following in detail the construction for the intersections of l, y and p of the topaz crystal, Fig. 223.

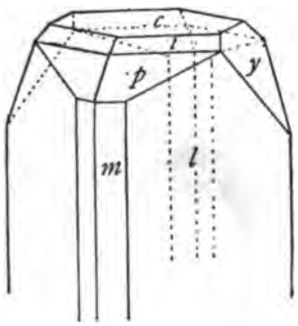
In Fig. 222, $A\bar{A}$, $B\bar{B}$ and $C\bar{C}$ form the projected axial cross of topaz.

The faces l, y and p are respectively $2a : b : \infty c$, $\infty a : b : 4c$ and $a : b : c$. If these are moved each parallel to itself until they intersect c at unity their symbols (dividing by the coefficients of c in each case) will be $0a : 0b : c$, $\infty a : \frac{1}{4}b : c$, $a : b : c$.

The Miller Indices are 120, 041, 111, their reciprocals are $1\frac{1}{2}\infty$, $\infty\frac{1}{4}1$, 111, and these, each divided by the third, reduce to 001, $\infty\frac{1}{4}1$, 111, which are identical with the coefficients already obtained.

Their traces upon the plane AOB, Fig. 222, will be therefore respectively:

FIG. 223.



For l, the line $L\bar{L}$ through the center but parallel to its former position at which it cuts at $2a$ and b.

For y, the line $Y\bar{Y}$ parallel $A\bar{A}$ and intersecting at one fourth b.

For p the line AB intersecting the axes at a and b.

The lines $L\bar{L}$ and $Y\bar{Y}$ intersect at S; therefore SC is the direction of intersection of l and y.

The lines $L\bar{L}$ and AB intersect at L; therefore $\bar{L}C$ is the direction of intersection of l and p.

All other intersections may be obtained in the same manner on any axial cross.

Construction of the Figure.

The edge directions thus found are now to be united in ideal symmetry, yet so as to show, as far as possible, the relative development of the forms.

A second axial cross is drawn parallel to that used in determining the edge directions and these are transferred by triangles, care being taken that all corresponding dimensions are in their proper proportions and in accord with the planes of symmetry. *Generally it will be best to pencil in and verify the principal forms and later, to work in the minor modifying planes.*

The back (or dotted) half of most crystals can be obtained by marking the angles of the front half on tracing paper, turning the paper in its own plane 180° and pricking through. This is also a test of accuracy, for the outer edges, angle for angle, should coincide.

GRAPHIC DETERMINATION OF INDICES AND AXIAL ELEMENTS.

The stereographic projection having been made as described, page 14, the position of the faces 001, 010, 100 (pinacoids) being known and a plane having been chosen as 111 or two planes as two of 110, 101 and 011; it is possible to determine graphically the axial elements and the indices of all other occurring faces with sufficient accuracy to ascertain the true rational indices.

A. SIMPLE DEVICE FOR THE DETERMINATION OF INDICES BY ZONE RELATIONS.

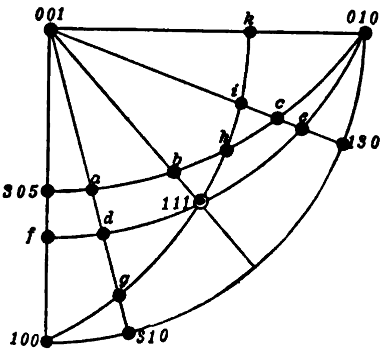
A zone is a series of faces which intersect in parallel edges. In the projection all poles of a zone are projected in the same great circle and it is assumed that all prominent zones through the 001, 010 or 100 poles have been drawn.

If two of the indices of any face of a zone are zero, the ratio of the corresponding indices is constant for all faces of the zone. Hence:

For a zone through 001 or 00(0)1, h/k is constant for all faces.
For a zone through 100 or 10($\bar{1}$)0, k/l is constant for all faces.
For a zone through 010 or 01($\bar{1}$)0, h/l is constant for all faces.

The indices of a face at the intersection of two such zones will result if in each zone a second face is known. The desired values may be obtained by writing the indices of the two known faces, omitting the term in each not part of the constant ratio, and then multiplying the corresponding pair for one index and diagonal pairs for the other two indices.

FIG. 224.



EXAMPLE.—In Fig. 224 let the pinacoids and (111), (310), (305), and (130), be known, to find the indices of planes projected

at *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*, *i*, *k*. All calculations are either like *h* in zones [010 305] and [100 111], or like *i* in zones [001 130] and [100 111].

$$\begin{array}{ccc} 3 & - & 5 \\ - & 1 & 1 \\ \hline 3 & 5 & 5 \end{array} \qquad h = (355) \qquad\qquad \begin{array}{ccc} 1 & 3 & - \\ - & 1 & 1 \\ \hline 1 & 3 & 3 \end{array} \qquad i = (133)$$

Similarly $a = (315)$, $b = (335)$, $c = (395)$, $d = (313)$, $e = (131)$, $f = (101)$, $g = (311)$ and $k = (011)$.

In the hexagonal system the third index is omitted.

EXAMPLE.—*hkil* lies in the zone $10\bar{1}0 : 02\bar{2}1$ and also in the zone $01\bar{1}0 : 11\bar{2}1$. Omitting i and writing the constant ratios as before, there result

$$\begin{array}{ccc} -2 & & 1 \\ 1 & - & 1 \\ \hline 1 & 2 & 1 \end{array} \qquad hkl = 121 \qquad\qquad hkil = 12\bar{3}1.$$

B. GRAPHIC DETERMINATION BY {hko}-, {okl}-, AND {hol} FACES.

For faces (*hkl*) the corresponding faces (*hko*), (*okl*) and (*hol*) are found by the zone circles through (001), (100) and (010) (Fig. 225).

FIG. 225.

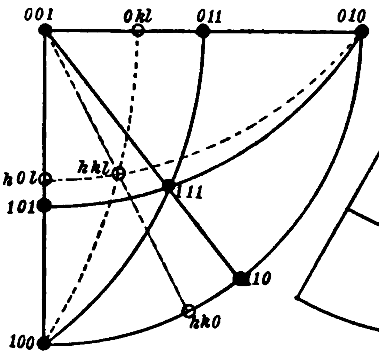
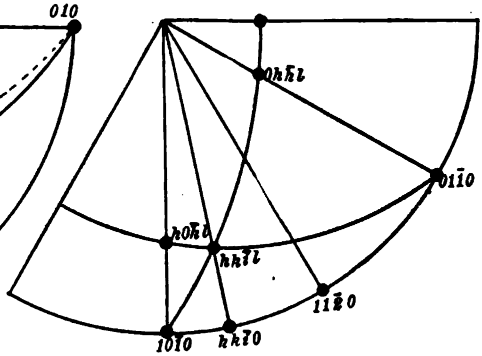


FIG. 226.



In the hexagonal system the {*hkil*} faces are found similarly by the zone circles through (0001), (10$\bar{1}$0) and (01$\bar{1}$0) (Fig. 226) and determining the corresponding (*hkio*), (*ohhl*) and (*hohl*) faces. It is then possible to read directly the ratios h/k, k/l and h/l, on a scale, the position of which can be found by a simple construction.

Graphic Determination of h/k.

In any system with axes at right angles (isometric, tetragonal or orthorhombic) the ratio of h/k can be graphically determined on the stereographic projection. For instance in Fig. 225 to find the ratio of h/k.

Find T, Fig. 227, the intersection of the radius through 110 and

FIG. 227.

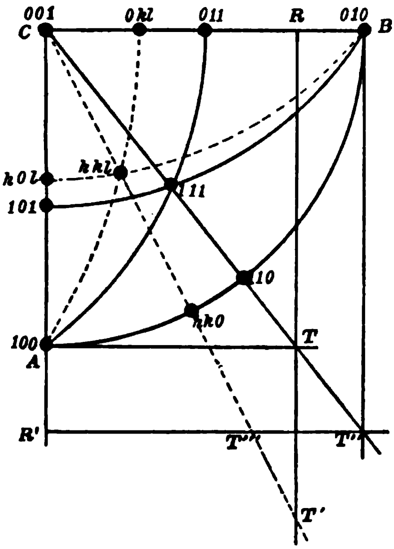
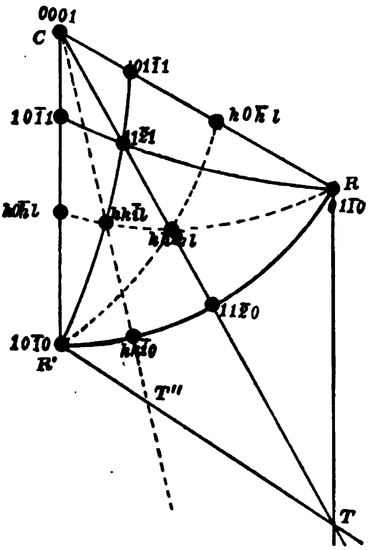


FIG. 228.



the tangent at A. Take RT parallel to CA as equal 1 (unity). Then the radius through any other pole as hkl will cut this line RT at a point T' such that $RT' = h/k$.

In the drawing $h/k = 1.5$.

In the hexagonal system similarly find T, the common intersection, Fig. 228, of the radius through $11\bar{2}0$ and the lines RT and $R'T$ parallel respectively to CR' and CR.

Take $RT = R'T$ as unity. Then the prolongation of the radius through any pole, $hk\bar{i}l$, cuts these lines in points T' (on RT not shown) and T'' such that

$$RT' = \frac{\text{first index}}{\text{second index}}; \quad R'T'' = \frac{\text{second index}}{\text{first index}}.$$

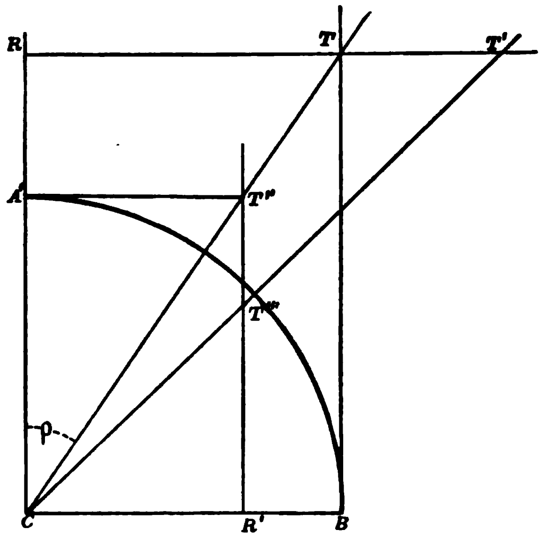
For the monoclinic and triclinic systems the constructions are a little more complex.*

* See *School of Mines Quarterly*, Vol. 24, pp. 18 and 20.

Graphic Determination of k/l.

For all isometric, tetragonal, orthorhombic or hexagonal crystals k/l may be determined graphically from the stereographic projection as follows: In the fourth quadrant of the projection lay off ρ * of 011 ($01\bar{1}1$ in hexagonal) from A', Fig. 229, and find T the intersection of the corresponding radius with the tangent at B. Take RT parallel CB as unity. Lay off from A' the angle ρ of any $0kl$ face (in hexagonal any $0h\bar{h}l$ face) and find the intersection T' of the corresponding radius with RT. Then is $RT' = k/l$.

FIG. 229.



In the drawing $k/l = 1.5$. If the determination of h/k given above relates to the same face then $h : k : l = 1.5 : 1 : 1/1.5$ or $9 : 6 : 4$ that is $hkl = 964$.

Graphic Determination of Elements.

Tetragonal $c = A'T''$, Fig. 229.
Hexagonal $c = A'T'' \times 0.866$, Fig. 229.
Orthorhombic $c = A'T''$, Fig. 229.
$\breve{a} = AT$, Fig. 227.

* See pages 6 and 14 for ρ.

PART II.

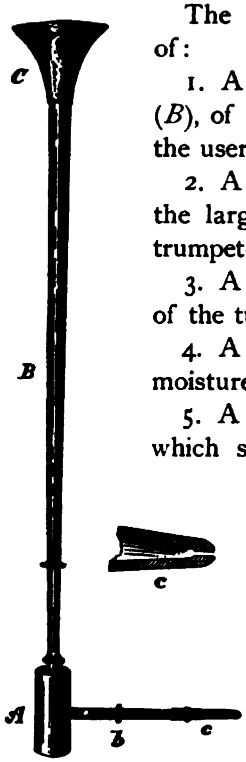
BLOWPIPE ANALYSIS.

CHAPTER X.

APPARATUS, BLAST, FLAME, ETC.

The Blowpipe.

FIG. 230.



The best form of blowpipe (Fig. 230) consists of:

1. A tapering tube of brass or German silver (*B*), of a length proportionate to the eyesight of the user.

2. A horn or hard rubber mouthpiece (*C*) at the larger end of the tube. This should be of trumpet-shape to fit against the lips.

3. A moisture chamber (*A*) at the smaller end of the tube connected by ground joints to:

4. A tapering jet (*b*) at right angles to the moisture chamber.

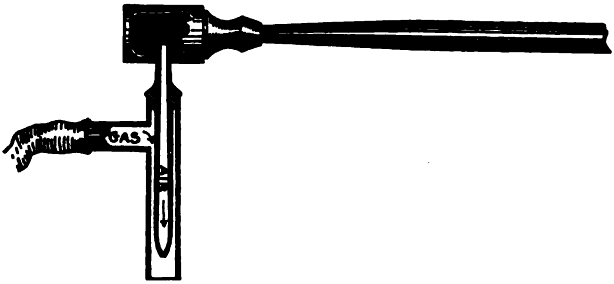
5. A tip of platinum or brass (*c*), shown enlarged, which should be bored from a solid piece, and with an orifice of 0.5 millimeter diameter. The tip is by far the most important part of the blowpipe, and, if correctly made, the flame produced will be perfectly regular and will not flutter.

When not in use the blowpipe should be so placed that the tip is supported free from contact. If the tip is clogged by smoke or otherwise it should be burned out or cleaned with the greatest care so as not to injure the regular form of the orifice.

Gas Blowpipe.

For most purposes the gas blowpipe, Fig. 231, is a convenient form and is extensively used. The flame is not quite so hot as that from rape-seed oil, but is sufficient to round the edges of a calamine splinter. Oxidation and reduction are easily obtained and the cleanliness and ease of control cause it to be preferred by

FIG. 231.



many. The ordinary blowpipe can be made into a gas blowpipe by means of an attachment to connect to the moisture chamber.

Blowpipe Lamps.

Bunsen Burner. — The simplest form of lamp for laboratory pur-

FIG. 232.

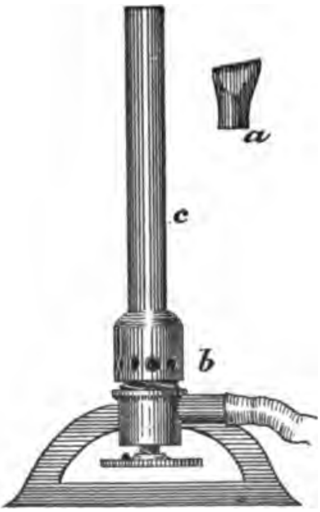
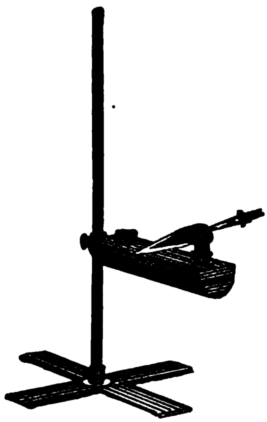


FIG. 233.



poses is the ordinary Bunsen burner, Fig. 232, using gas and furnished with a special top (*a*), or an inner tube shaped to spread

the flame. When used with the blowpipe the orifices (*b*) at the bottom of the burner should be closed, so that no air enters with the gas. A flame about 4 cm. high gives the best results.

The hottest flame and greatest variations in quantity and quality of flame are obtained from oils rich in carbon, such as refined rape-seed, or olive or lard oil, or from mixtures of turpentine and alcohol. These can be used in the field and where gas is not available. In some kinds of blowpipe work they are to be preferred to gas, but will not serve for bending glass or for heating without the blowpipe.

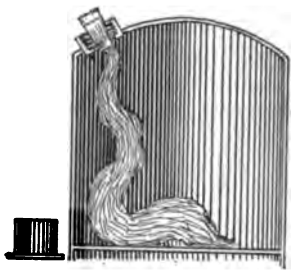
Berzelius Lamp. — A lamp with two openings, Fig 233, is generally used for oil.

The wick should be soft, close-woven and cylindrical, such as is used with Argand lamps. It should be folded and inserted with the opening toward the lower side of the brass holder.

To fill the lamp both caps are removed and the oil poured in through the smaller orifice. During work, the smaller cap is hung on the vertical rod; the larger is placed over the smaller orifice loosely, keeping out the dust, but admitting the needed air.

The lamp is lighted by blowing a flame up and across the wick. When well charred, the wick is carefully trimmed parallel to the brass holder.

FIG. 234



Fletcher Lamp. — The Fletcher blowpipe lamp, Fig. 234, gives good satisfaction, and a modified form, burning solid fats, tallow or paraffine, is especially adapted for field work.

Supports of Charcoal, Plaster, Etc.

Charcoal. — Charcoal made from soft woods, such as willow or pine, is used to support the substance and receive any coats or sublimates that may form, and, in a measure, is a reducing agent. A convenient size is 4 inches long, 1 inch broad, and ⅝ inch thick.

Plaster. — Plaster tablets are used for the same purpose. These are prepared by making a paste of plaster of Paris and water, just thick enough to run, which is spread out upon a sheet of oiled glass and smoothed to a uniform thickness (⅛″ to ¼″) by another smaller sheet of glass, which may be conveniently handled by gumming a large cork to one side and using it as a plasterer's trowel.

While still soft, the paste is cut with a knife into uniform slabs, 4″ by 1½″. It is then dried, after which the tablets are easily detached.

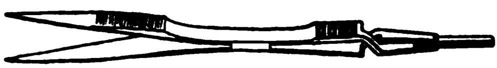
Aluminum and Glass. — Ross used supports of aluminum plate and Goldschmidt has recommended catching the sublimates on glass plates upon which they can be microscopically examined or submitted to wet treatment.

Miscellaneous Apparatus:

Each student should have at his desk, in addition to blowpipe, blowpipe-lamp, charcoal and plaster:

FORCEPS, with platinum tips for fusion tests. The most con-

FIG. 235.



venient form is shown, Fig. 235, the platinum ends projecting at least three fourths of an inch.

PLATINUM WIRE AND HOLDER. — Wire of the thickness of about one half millimeter. The handle for holding this is sometimes only a short piece of small glass tubing, into the end of which the wire is fused. A holder in which the wires can be changed and with a receptacle for a stock of wires, is more convenient.

FIG. 236.

REAGENT BOTTLES. — Four 2-oz. wide-mouthed bottles; for borax, soda, salt of phosphorus, and bismuth flux will be needed at all times. It is better to have at least eight such bottles in a convenient stand.

ANVIL. — Slab of polished steel, about 1½″ by 1½″ by ½″.

HAMMER. — Steel, with square face, ⅜″ or ½″. As in Fig. 236.

CLOSED AND OPEN TUBES.

CUPEL HOLDER AND CUPELS, for silver determination.

Other important pieces of apparatus are: bar magnet, with chisel edge; trays, for dirt and for charcoal; lens, knife, and watch glasses; blue and green glasses; steel forceps and lamp scissors for trimming wick; cutting pliers, for cutting bits from minerals to

be tested; agate mortar and pestle, which can be obtained 1¼″ in diameter; small porcelain dishes, ivory spoon and dropping tube.

BLAST AND FLAME.

The Blast.

The blast is produced by the muscles of the distended cheeks, and not by the lungs.

It is best to sit erect, with the blowpipe held lightly but firmly in the right hand, and with the elbows against the sides. Then, with the cheeks distended and the mouth closed, place the mouth-piece against the lips, breathe regularly through the nose, and allow air to pass into the pipe through the lips. From time to time, as needed, admit air to the mouth from the throat. In this manner, after learning to breathe through the nose while keeping the cheeks distended, a continuous blast can be blown without fatigue.

The Flame.

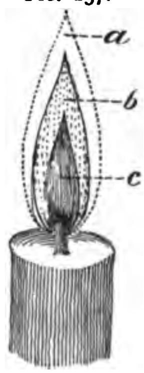
A LUMINOUS FLAME (Fig. 237) usually shows three distinct portions.

1. A very hot non-luminous veil, *a*, of carbon dioxide and free oxygen.

2. A yellow luminous mantle, *b*, of burning gases and incandescent carbon.

3. An interior dark cone, *c*, of unburned gases, not always visible.

FIG. 237.



Oxidation and Oxidizing Flame.

The oxidizing flame is non-luminous, for luminosity indicates unconsumed carbon, and hence a reducing action.

To produce such a flame, place the tip of the blowpipe almost touching the top of the burner, or the wick, and extending in ⅓ the breadth of the flame; blow parallel to the burner top or wick until there is produced a clear blue flame nearly an inch long. This blue flame is weakly reducing, but just beyond the blue at *a* (Fig. 238) is an intensely hot, nearly colorless zone, which is strongly oxidizing, and the bead is held in this usually as far from the tip of the blue flame as the bead can be kept fluid. If the substance to be oxidized is supported on charcoal, a weak blast must be used.

With the gas blowpipe all that is necessary is to avoid an excess of gas. The blue flame is, as before, surrounded by the oxidizing colorless mantle.

Testing Purity of Oxidizing Flame.— A loop, Fig. 239, about 3 mm. in diameter, is made in platinum wire by bending it around

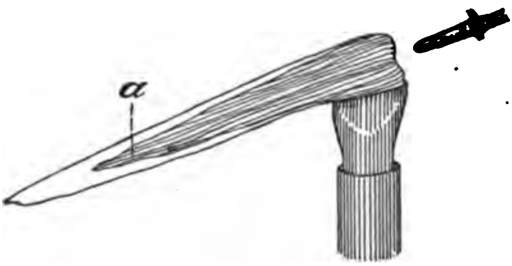
FIG. 238.

FIG. 239.

a pencil point, or with the forceps, so that the end meets but does not cross the straight part. This loop is heated and dipped into the flux, and the portion of flux that adheres is fused to a clear bead, more being added until the bead is of good full shape.*

Molybdic oxide, MoO_3, is then dissolved in the bead at the tip of the blue flame, giving a brown to black bead from production of MoO_2 but, if moved to *a*, Fig. 238, the color is readily removed by the reoxidation of the MoO_2 and the bead made colorless.

FIG. 240.



Reduction and the Reducing Flames.

To blow the yellow reducing flame, Fig. 240, place the tip of the blowpipe one eighth of an inch above and back of the middle of the flame, blow strongly parallel to the burner top or wick, and turn the entire flame in the direction of the blast.

* When the flux is salt of phosphorus, the wire should be held over the flame so that the ascending hot gases will help to retain the flux upon the wire.

The blast must be continuous; too strong to produce a sooty flame, and not strong enough to oxidize by excess of air.

The blue flame also is reducing because of the carbon monoxide it contains, but it is not generally as effective.

With the gas blowpipe reduction is obtained by using a larger flame and inserting the bead within the blue; or with large excess of gas a yellow reducing flame may be obtained.

Testing Purity of Reducing Flame. — Manganese dioxide, MnO_2, is dissolved in a borax bead in the oxidizing flame; if only a little is used the bead is violet red when cold, and may be made colorless in the reducing flame. Or cupric oxide or oxide of nickel may be dissolved in a borax bead until the bead is opaque, and then reduced on charcoal to a clear bead and a metallic button.

CHAPTER XI.

OPERATIONS OF BLOWPIPE ANALYSIS.

Fusion.

THE hottest portion of the flame is just beyond the tip of the blue flame. In some instances, noticeably certain iron ores, substances infusible in the oxidizing flame are fusible in the reducing flame.

The test will be differently made, according to the material.

(*a*) If metallic or reducible, treat in a shallow hole on charcoal, using a fragment of the substance the size of a pin's head.

(*b*) If stony or vitreous, treat a small sharp-edged fragment in the platinum forceps, at the tip of the blue flame, directing the flame upon the point.

(*c*) If in powder, or with a tendency to crumble, grind and mix with water to fine paste, spread thin on coal and dry, and, if coherent, hold in the forceps. If not coherent dip a moistened platinum wire in the powder, and treat the adhering powder in the flame.

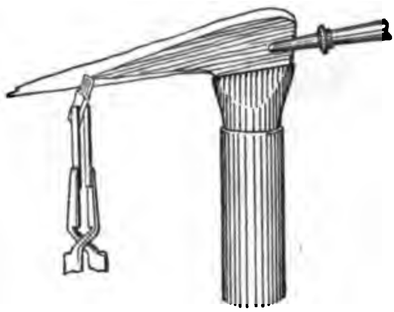
There will be noted both the *degree* of fusibility and manner of fusion.

The *degree* of fusibility is stated in much the same way as the hardness by comparing it with a scale of fusibility. It is generally, however, sufficient to class a mineral as simply easily fusible, fusible, difficultly fusible, or infusible. For purposes of comparison, the following scale, suggested by v. Kobell, is usually adopted:

1. *Stibnite*, coarse splinters fuse in a candle flame.
2. *Natrolite*, fine splinters fuse in a candle flame.
3. *Garnet* (*Almandite*), coarse splinters easily fuse before the blowpipe.
4. *Actinolite*, coarse splinters fuse less readily before the blowpipe.
5. *Orthoclase*, only fused in fine splinters or on thin edges before the blowpipe.
6. *Calamine*, finest edge only rounded in hottest part of flame.
7. *Quartz*, infusible, retaining the edge in all its sharpness.

The trial should always be made on small and fine pointed fragments. Penfield recommends using a standard size about 1 mm. in diameter and 4 mm. long. The fragment should project beyond the platinum as in Fig. 241, so that heat may not be drawn off by the platinum, and the flame directed especially upon the point. It is always well to examine the splinter with a magnifying glass, before and after heating, to aid the eye in determining whether the edges have or have not been rounded by the heat.

FIG. 241.



The manner of fusion may be such as to result in a glass or slag which is clear and transparent, or white and opaque, or of some color, or filled with bubbles. There may be a frothing or intumescence, or a swelling and splitting (exfoliation). In certain instances the color and form may change without fusion, etc.

Flame Coloration.

During the fusion test the non-luminous veil is sometimes unchanged, but it is often enlarged and colored by some volatilizing constituent. There is frequently a bright yellow coloration due to sodium salts, but this gives place to the color proper.

The flame is best seen in a dark room or against a black background, such as a piece of charcoal, and is often improved by hydrochloric acid and occasionally by other reagents.

Some elements color the flame best at a gentle heat, others only at the highest heat attainable. A good method to cover all cases is to dip the end of a flattened platinum wire first in hydrochloric acid and then in the finely powdered substance and hold it first in the mantle flame near the wick and then at the hottest portion at the tip of the blue flame. It is possible in this way to obtain two distinct flames such as the red of calcium and the blue from copper chloride.

The colors can also often be seen to decided advantage by simply holding the wire in the non-luminous flame of a Bunsen burner or even in the flame of an alcohol lamp.

Flame tests for Ca, Sr and Ba are not usually obtainable from silicates.

The important flame colorations are:

Yellows.

YELLOW. — Sodium and all its salts. Invisible with blue glass.

Reds.

CARMINE. — Lithium compounds. Masked by soda flame. Violet through blue glass. Invisible through green glass.

SCARLET. — Strontium compounds. Masked by barium flame. Violet red through blue glass. Yellowish through green glass.

YELLOWISH. — Calcium compounds. Masked by barium flame. Greenish gray through blue glass. Green through green glass.

Greens.

YELLOWISH. — Barium compounds, molybdenum sulphide and oxide; borates especially with sulphuric acid or boracic acid flux.

PURE GREEN. — Compounds of tellurium or thallium.

EMERALD. — Most copper compounds without hydrochloric acid.

BLUISH. — Phosphoric acid and phosphates with sulphuric acid.

FEEBLE. — Antimony compounds. Ammonium compounds.

WHITISH. — Zinc.

Blues.

LIGHT. — Arsenic, lead and selenium.

AZURE. — Copper chloride.

WITH GREEN, — Copper bromide and other copper compounds with hydrochloric acid.

Violet.

Potassium compounds. Obscured by soda flame. Purple red through blue glass. Bluish green through green glass. In silicates improved by mixing the powdered substance with an equal volume of powdered gypsum.

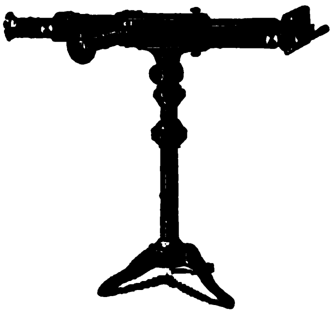
USE OF THE SPECTROSCOPE.

When salts of the same metal are volatilized in the non-luminous flame of a Bunsen burner the spectra produced, on decomposing the resultant light by a prism, will show lines identical in color, number and relative position. Salts of different metals will yield different lines.

Although, with pure salts, the already described flame colorations are generally distinct and conclusive, it will frequently happen that in silicates or minerals containing two or more reacting

substances the eye alone will fail to identify the flame coloration. It is well therefore to supplement the ordinary flame tests by spectroscopic observation. In the blowpipe laboratory the chief use of the spectroscope will be to identify the metals of the potassium and calcium families singly or in mixtures. For this purpose the direct vision spectroscope of Hoffman, Fig 242, is the most convenient.

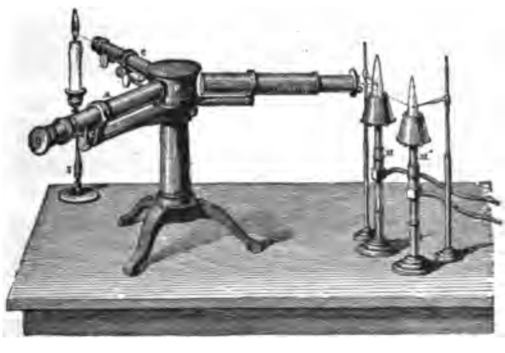
FIG. 242.



The substance under examination should be moistened with hydrochloric acid and brought on a platinum wire into the non-luminous flame of the Bunsen burner as in the ordinary flame test. In viewing the flame through the properly adjusted spectroscope certain bright lines will be seen, and by comparing these with the chart, Fig. 245, or with substances of known composition, the nature of the substance may be determined. The sodium line will almost invariably be present and the position of the other lines will be best fixed by their situation relative to this bright yellow line.

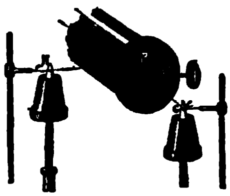
The more ordinary form of spectroscope, Fig. 243, has special

FIG. 243.



advantages in allowing an easy comparison of flames. *A* is the observation telescope, *B* the collimator through which the light from the flames *M* and *M'* is sent as parallel rays through the prism

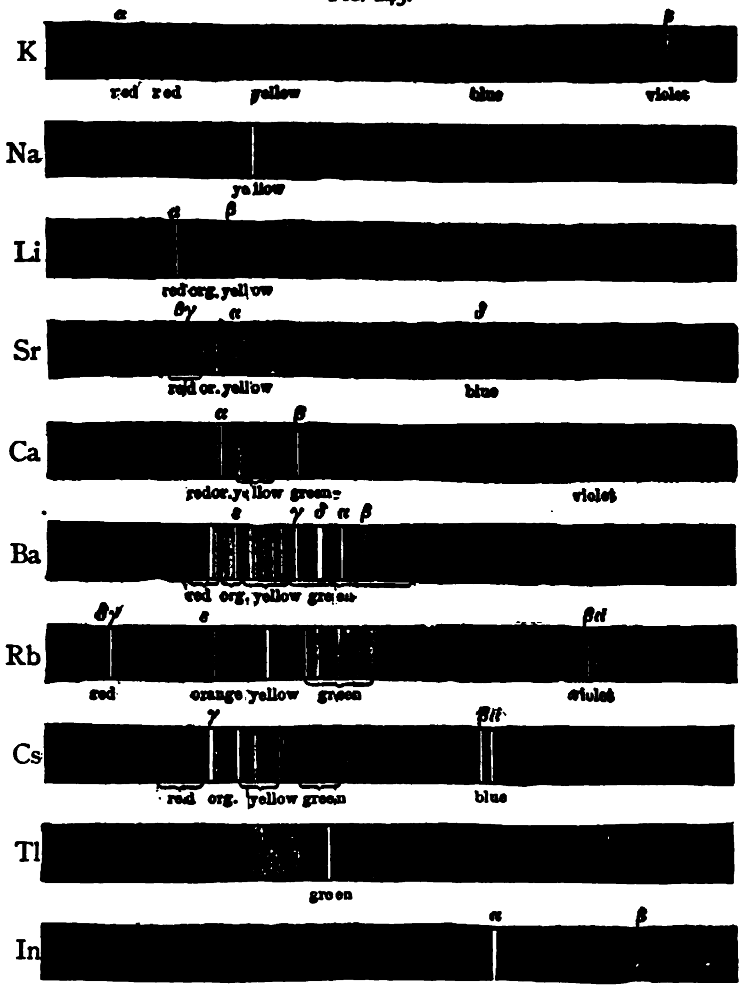
FIG. 244.



P to the telescope *A*. The third telescope *C* sends the image of a micrometer scale to *A* by which the relative distance apart of the lines is judged.

Fig. 244 shows an enlarged view of the collimator *B*. By means of the little rectangular prism *i* the light from a second flame *H*, placed at one side, is sent through the collimator and its spectrum obtained side by side with that from the flame *G*.

FIG. 245.



In this manner the spectrum of an unknown substance may be compared with that of one of known composition and if lines of the unknown coincide with those of the known substance the identity of at least one of its constituents is established.

The chart (Fig. 245) and brief description of spectra of substances giving distinct lines with the Bunsen flame will be of service.

POTASSIUM — two red lines and one violet line.

SODIUM — a single bright yellow line, which with higher dispersion is resolved into two lines. Almost always present from the small amounts of sodium in dust.

LITHIUM — one very bright deep red line and a faint line in the orange.

STRONTIUM — a number of characteristic red lines and one blue line.

CALCIUM — a bright red, and a bright green line, with fainter red to yellow lines and a line in the violet.

BARIUM — a number of yellow and green lines.

RUBIDIUM — two violet and two red lines with several less prominent lines in the orange, yellow and green.

CÆSIUM — two distinct blue lines and one orange line.

THALLIUM — one characteristic green line.

INDIUM — an indigo blue line and a violet line.

VOLATILIZATION.

In blowpipe analysis, antimony, arsenic, cadmium, zinc, tin, lead, mercury and bismuth are always determined by securing sublimates of either the metals themselves or of some volatile oxide, iodide, etc.

Other elements and compounds, such as sulphur, selenium, tellurium, osmium, molybdenum, ammonia, etc., are also volatilized and in part determined during volatilization as odors or by sublimates. Certain other compounds, particularly chlorides of sodium and potassium and of some other metals, such as copper, tin and lead, yield sublimates ordinarily disregarded.

Volatilization tests are commonly obtained on charcoal, or plaster or in open and closed tubes.

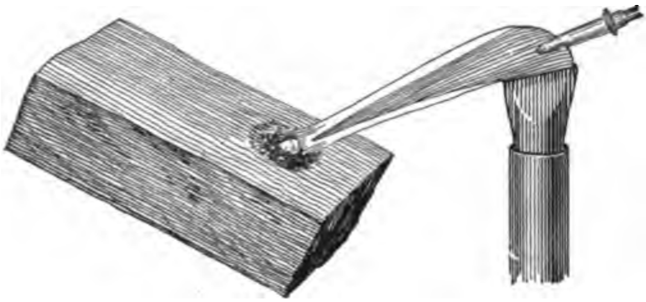
Treatment on Charcoal.

A shallow cavity, just sufficient to prevent the substance slipping, is bored at one end of the charcoal and a small fragment or a very little of the powdered substance is placed in it. The charcoal

is held in the left hand, so that the surface is at right angles to the lamp but tipped vertically at about 120° to the direction in which the flame is blown.

A gentle oxidizing flame is blown, the blue flame not touching the substance, but being just behind and in a line with it. After a

FIG. 246.



few moments the test is examined and all changes are noted, such as position and color of sublimates, color changes, odors, decrepitation, deflagration, formation of metal globules or magnetic particles. The heat is then increased and continued as long as the same reactions occur, but if, for instance, a sublimate of new color or position is obtained, it is often well to remove the first sublimate either by transferring the substance to another piece of charcoal or by brushing away the first formed sublimate after its satisfactory identification.

The same steps should then be followed using the reducing flame.

The sublimates differ in color and position on the charcoal; some are easily removed by heating with the oxidizing flame, some by the reducing flame, some are almost non-volatile, and some impart colors to the flame.

Treatment on Plaster Tablets.

Experience has shown that the sublimates obtained on charcoal and plaster supplement each other. The method of using is precisely the same and white sublimates are easily examined by first smoking the plaster surface by holding it in the lamp flame.

The coatings differ in position, and to some extent in color.

Plaster is the better conductor, condenses the oxides closer to the assay, and therefore, the more volatile coatings are thicker and more noticeable on plaster, while the less volatile coatings are more noticeable when spread out on charcoal. Charcoal supplements the reducing action of the flame, and therefore is the better support where strong reduction is desired.

Comparison of Important Sublimates on Charcoal and Plaster.*

I. Without Fluxes.—Treated First in O. F., then in R. F.

ARSENIC.—White volatile coat. On smoked plaster it is crystalline and prominent; on charcoal it is fainter and less distinct, but the odor of garlic is more marked. Deposits at some distance from assay. Fumes invisible close to assay.

ANTIMONY.—White pulverulent volatile coat, more prominent on charcoal. Is deposited near assay and the fumes are visible close to assay after removal of flame.

SELENIUM.

On Charcoal.—Horse-radish odor and a steel-gray coat.

On Plaster.—Horse-radish odor, brick-red to crimson coat.

TELLURIUM.

On Charcoal.—White coat with red or yellow border.

On Plaster.—Deep brown coat.

CADMIUM.

On Charcoal.—Brown coat surrounded by peacock tarnish.

On Plaster.—Dark brown coat shading to greenish-yellow and again to dark brown.

MOLYBDENUM.—Crystalline yellow and white coat with an outer circle of ultramarine blue. Most satisfactory on plaster.

LEAD.— } Yellow sublimate with outer fringe of white. More
BISMUTH.— } noticeable on charcoal than on plaster.

ZINC.—White, not easily volatile coat, yellow while hot. Best on charcoal.

TIN.—White non-volatile coat close to assay, yellowish while hot. Best on charcoal.

---

* Certain compounds give a white coating before the blowpipe which at times cause confusion. Among these are many chlorides and the sulphate of lead. Galena and lead sulphides also give white sublimates which must not be confused with the arsenic or antimony coats.

II. With Bismuth Flux.*

LEAD.

On Plaster.—Chrome yellow coat.

On Charcoal.—Greenish-yellow, equally voluminous coat.

BISMUTH.

On Plaster.—Chocolate-brown coat, with an underlying scarlet; with ammonia it becomes orange-yellow, and later cherry-red.

On Charcoal.—Bright red band with a fringe of yellow.

MERCURY.

On Plaster.—Scarlet coat with yellow, but if quickly heated is dull yellow and black.

On Charcoal.—Faint yellow coat.

ANTIMONY.

On Plaster.—Orange coat stippled with peach-red.

On Charcoal.—Faint yellow coat.

ARSENIC.

On Plaster.—Yellow and orange coat, and not usually satisfactory.

On Charcoal.—Faint yellow coat.

TIN.

On Plaster.—Brownish-orange coat.

On Charcoal.—White coat.

The following tests show only on the plaster:

SELENIUM.—Reddish-brown, nearly scarlet.

TELLURIUM.—Purplish-brown with darker border.

MOLYBDENUM.—Deep ultramarine blue.

III. With Soda (Sodium Carbonate or Bicarbonate).

Soda on charcoal exerts a reducing action partly by the formation of sodium cyanide, partly because the salts sink into the charcoal and yield gaseous sodium and carbon monoxide. The most satisfactory method is to mix the substance with three parts of the moistened reagent and a little borax; then spread on the charcoal and treat with a good reducing flame until everything that can be absorbed has disappeared. Moisten the charcoal with water, break out and grind the portion containing the charge. Wash away the lighter part and examine the residue for scales and magnetic particles.

* Two parts of sulphur, one part of potassium iodide, one part of acid potassium sulphate.

The reduction may result in:

1. *Coating, but no reduced metal.*

   Volatile white coating and garlic odor, ... **As.**

   Reddish-brown and orange coating with characteristic variegated border, ... **Cd.**

   Non-volatile coating, yellow hot and white cold, . . **Zn.**

   Volatile steel-gray coating and horseradish odor, . **Se.**

   Volatile white coating with reddish border, . . . **Te.**

2. *Coating with reduced metal.*

   Volatile thick white coating and gray brittle button, . **Sb.**

   Lemon-yellow coating and reddish-white brittle button, **Bi.**

   Sulphur-yellow coating and gray malleable button, . **Pb.**

   Non-volatile white coating, yellow hot, and malleable white button, ... **Sn.**

   White coating, made blue by touch of R. F., and gray infusible particles, ... **Mo.**

3. *Reduced metal only.*

   Malleable buttons, ... **Cu, Ag, Au.**

   Gray magnetic particles, ... **Fe, Co, Ni.**

   Gray non-magnetic infusible particles, **W, Pt, Pd, Ir, Rh.**

The carbonate combines with many substances forming both fusible and infusible compounds. Many silicates dissolve with a little of the reagent, but with more are infusible; a few elements form colored beads with the reagent, especially on platinum.

The residue left after heating may contain malleable metallic beads of copper, lead, silver, tin or gold. It may consist of a brittle easily fusible button of bismuth, antimony, or the sulphide, arsenide or antimonide of some metal. It may be magnetic from the presence of iron, cobalt or nickel or it may show an alkaline reaction, when touched to moistened red litmus or tumeric paper, indicating the presence of some member of the potassium or calcium group of metals.

Infusible Compounds.—Mg, Al, Zr, Th, Y, Gl.

Fusible Compounds.—SiO_2 effervesces and forms a clear bead that remains clear on cooling if the reagent is not in excess.

TiO_2 effervesces and forms a clear yellow bead crystalline and opaque on cooling.

WO_3 and MoO_3 effervesce but sink in the charcoal.

Ba, Sr, Ta, V, Nb sink into the charcoal.

Ca fuses, then decomposes, and the soda sinks into the charcoal.

Colored Beads.—Mn forms a turquois or blue-green opaque bead with soda on platinum wire in the oxidizing flame.

Cr forms a chrome-yellow opaque bead with soda on platinum wire in the oxidizing flame, which becomes green in reducing flame.

Sulphur Reaction.—If a little of the residue, with some of the charcoal beneath, is taken up upon the point of a knife and placed upon a wet silver coin, the coin will be blackened if sulphur was present as a sulphide. Sulphates and other sulphur compounds will also give the same reaction after thorough fusion. The test should always be made on a fresh piece of charcoal.

IV. With Metallic Sodium.

Reducing effects which are obtained with soda only by hard blowing may be accomplished by the use of metallic sodium immediately and with the greatest ease. The metal should be handled carefully and not allowed to come in contact with water. It should be kept in small tightly closed bottles, and if kept covered with naphtha, which is not necessary, care should be taken that the naphtha is not exposed to fire.

A cube of sodium about a quarter-inch in diameter is cut off with a knife and hammered out flat. The powdered substance is placed upon the sodium, pressed into it and the whole moulded into a little ball with a knife blade. This sodium ball should not be touched with the fingers, for if some oxides are present, such as lead oxide, spontaneous combustion may take place. After placing the sodium ball on the charcoal it should be touched carefully with a match or with the Bunsen flame. A little flash ensues and the reduction is accomplished. The residue can now be safely heated with the reducing flame of the blowpipe, any reduced metal collected together and the sodium compounds volatilized or absorbed by the charcoal. When present in sufficient quantity, beads of the malleable metals can be obtained immediately from almost any of their mineral compounds; metals, like zinc and tin, which require reduction before volatilization yield their sublimates with comparative ease; and if a little of the charcoal beneath the assay is placed on a wet silver coin the sulphur reaction will be obtained if sulphur was present.

In general the results are the same as outlined for soda but are much more easily secured.

Even silica, silicates, borates, etc., are reduced but are generally identified by other means.

These reactions are not successful on plaster tablets on account of their non-absorbent character.

Tests in Closed Tubes.

A plain narrow glass tube about 4 inches by ¼ inch and closed at one end is best. The usual purposes are to note the effects of heat without oxidation, and to effect fusions with such reagents as $KHSO_4$ or $KClO_3$.

FIG. 247.

Enough of the substance is slid down a narrow strip of paper, previously inserted in the tube, to fill it to the height of about one half inch; the paper is withdrawn and the slightly inclined tube, Fig. 247, heated at the lower end gradually to a red heat. The results may be: evolution of water, odorous and non-odorous vapors, sublimates of various colors, decrepitation, phosphorescence, fusion, charring, change of color, and magnetization.

Acid or alkaline moisture in the upper part of tube, ...	H_2O.
Odorless gas that assists combustion (nitrates, chlorates and per oxides),.	O.
Pungent gas that whitens lime water, ...	CO_2.

Odors.

Odor of prussic acid, ...	CN.
Odor of putrid eggs, ...	H_2S.
Odor that suffocates, fumes colorless, bleaching action, .	SO_2.
Odor that suffocates, fumes violet, ...	I.*
fumes brown, ...	Br.
fumes greenish yellow, . .	Cl,
fumes etch the glass, . .	F.
Odor of nitric peroxide, fumes reddish-brown, .	NO_2.
Odor of ammonia, fumes colorless or white, . .	NH_3.†

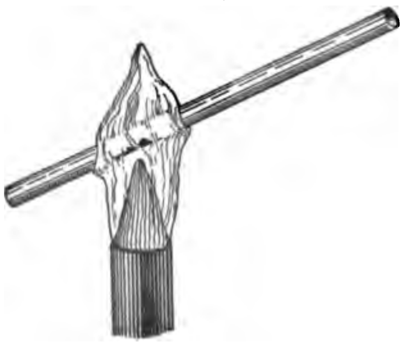
* I, Br, Cl, F and N_2O_5 are assisted by mixing substance with acid potassium sulphate. † NH_3, Hg, As, Cd are assisted by mixing with soda.

Sublimates.

Sublimate white, fusing yellow, ...	$PbCl_2$.
fusing to drops, disagreeable odor,	Os.
and volatile, ...	NH_4 (salts).
yellow hot, infusible, . . .	HgCl.
yellow hot, fusible, . . .	$HgCl_2$.
fusible, needle crystals, . .	Sb_2O_3.
volatile, octahedral crystals, . .	As_2O_3.
fusible, amorphous powder, . .	TeO_2.
Sublimate mirror-like, collects in globules, . .	Hg.
does not collect in globules, .	As, Cd, Te.
Sublimate red when hot, yellow cold, . . .	S.
Sublimate dark red when hot, reddish-yellow cold, .	As_2S_3.
Sublimate black when hot, reddish-brown cold, .	Sb_2S_3.
Sublimate black, but becomes red when rubbed, .	HgS.
Sublimate red to black, but becomes red when rubbed, ...	Se.
Color of substances changes	
from white to yellow, cools yellow, . . .	PbO.
from white to yellow, cools white, . . .	ZnO.
from white to dark yellow, cools light yellow, .	Bi_2O_3.
from white to brown, cools yellow, . . .	SnO_2.
from white to brown, cools brown, . . .	CdO.
from yellow or red to darker, after strong heat, cools green, ...	Cr_2O_3.
from red to black, cools red, ...	Fe_2O_3.
from blue or green to black, cools black, .	CuO.

Tests in Open Glass Tubes.

Fig. 248.



By using a somewhat longer tube, open at both ends and held in an inclined position, a current of air is made to pass over the heated substance, and thus many substances not volatile in themselves absorb oxygen and release volatile oxides. The substance should be in state of powder

Place the assay near the lower

end of the tube, Fig. 248, and heat gently, and then strongly, increasing the air current by holding the tube more and more nearly vertical.

Odor that suffocates, bleaching action,	SO_2,	indicating	**S.**
Odor of rotten horseradish,	SeO_2,	"	**Se.**
Odor of garlic,	As_2O_3,	"	**As.**
Sublimate white volatile octahedral crystals,	As_2O_3,	"	**As.**
Sublimate white partially volatile, fusible to yellow drops, pearl gray cold,	PbOCl,	"	**$PbCl_2$.**
Sublimate white non-volatile powder, dense fumes,	Sb_2O_3,	"	**Sb.**
Sublimate white non-volatile powder, fusible to colorless drops,	TeO_2,	"	**Te.**
Sublimate white non-volatile powder, fusible to yellow drops, white when cold,	$PbSO_4$,	"	**PbS.**
Sublimate white non-volatile fusible powder,	$BiSO_4$,	"	**BiS.**
Sublimate gray, red at distance,	SeO_2,	"	**Se.**
Sublimate yellow hot, white cold, crystalline near the assay, blue in reducing flame,	MoO_3,	"	**Mo.**
Sublimate brown hot, yellow cold, fusible,	Bi_2O_3,	"	**Bi.**
Sublimate metallic mirror,		"	**Hg.**

Bead Tests with Borax and with Salt of Phosphorus.

Preliminary to bead tests, many compounds, sulphides, arsenides, arsenates, etc., may be converted into oxides by roasting as follows:

Treat in a shallow cavity on charcoal at a dull red heat, never allowing the substance to fuse or even sinter. Use a feeble oxidizing flame to drive off sulphur, then a feeble reducing flame to reduce arsenical compounds, then reheat in an oxidizing flame. Turn, crush, and reroast until no sulphurous or garlic odor is noticeable.

Sodium tetraborate or borax may be considered as made up of sodium metaborate and boron trioxide. The boron trioxide at a high temperature combines with metallic oxides, driving out volatile acids, and by the aid of the oxidizing flame the resulting borates fuse with the sodium metaborate to form double borates which are often of a characteristic color. The color may differ when hot and cold and according to the degree of oxidation and reduction.

Sodium ammonium phosphate, or salt of phosphorus, by fusion loses water and ammonia and becomes sodium metaphosphate. The sodium metaphosphate at high temperatures combines with metallic oxides to form double phosphates and pyrophosphates, which like the double borates are frequently colored, although the colors often differ from those obtained with borax.

A bead of either flux is made on platinum wire as described on page 80, and the substance is added gradually to the warm bead and fused with it in the oxidizing flame. The ease of dissolving, effervescence, color, change of color, etc., should be noted.

We may greatly simplify the tabulation of results by the following division:

1. *Oxides which Color neither Borax or Salt of Phosphorus, or at Most Impart a Pale Yellow to the Hot Bead when Added in Large Amounts.*

OXIDES OF	NOTICEABLE DISTINCTIONS.
ALUMINUM.	—Cannot be flamed opaque.
ANTIMONY.	—Yellow hot in oxidizing flame, flamed opaque gray in reducing flame, on charcoal with tin black. Expelled by reducing flame in time.
BARIUM.	—Flamed opaque white.
BISMUTH.	—Like antimony.
CADMIUM.	—Like antimony, but not made black by fusion with tin.
CALCIUM.	—Like barium.
LEAD.	—Like antimony, but not made black by fusion with tin.
MAGNESIUM.	—Like barium.
SILICON.	—Only partially dissolved in salt of phosphorus.
STRONTIUM.	—Like barium.
TIN.	—Like aluminum.
ZINC.	—Like antimony, but not made black by fusion with tin.

2. *Oxides which Impart Decided Colors to the Beads.*

The colors in hot and cold beads of both fluxes and under both oxidation and reduction are shown in the following table. The abbreviations are: sat = saturated; fl = flamed; op = opaque.

Hot and cold relate to same bead; *hot* and *cold* to larger amounts of the oxide.

BORAX BEADS.

Oxides of		Violet.	Blue.	Green.	Red.	Brown.	Yellow.	Col'l'ss
Chromium,	O.F.			cold	*hot*		hot	
	R.F			hot, cold				
Cobalt,	O.F.		hot, cold					
	R.F.		hot, cold					
Copper,	O.F.		cold	hot				
	R.F.				*cold* (op.)	cold		hot
Iron,	O.F.				*hot*		*hot, cold*	cold
	R.F.			hot, cold				
Manganese,	O.F.	hot cold						
	R.F.					*cold*		hot, cold
Molybdenum,	O.F				hot (sat.)		hot	cold
	R.F.					hot, cold		
Nickel,	O.F.	hot				cold		
	R.F.							hot, cold
Titanium,	O.F		flamed				*hot*	hot, cold
	R.F.					*hot, cold*	hot, cold	
Tungsten,	O.F.						*hot* (sat.)	hot, cold
	R.F.					cold	hot	cold
Uranium,	O.F.				hot		hot, cold(fl.)	
	R.F.			hot, cold				
Vanadium,	O.F.						*hot, cold*	hot, cold
	R.F.			cold		hot		

SALT OF PHOSPHORUS BEADS.

Oxides of		Violet.	Blue.	Green.	Red.	Brown.	Yellow.	Col'l'ss
Chromium,	O.F.			cold	hot			
	R.F.			cold	hot			
Cobalt,	O.F.		hot, cold					
	R.F.		hot, cold					
Copper,	O.F.		cold	hot				
	R.F.		hot		cold (op.)			
Iron,	O.F.				*hot*	cold	hot, *cold*	cold
	R.F.				*hot, cold*	cold	hot	cold
Manganese,	O.F.	hot, cold						
	R.F.							hot, cold
Molybdenum,	O.F.			hot				cold
	R.F.			hot, cold				
Nickel,	O.F.				hot		cold	
	R.F.				hot		cold	
Titanium,	O.F.						*hot*	hot, cold
	R.F.	cold					hot	
Tungsten,	O.F.						hot (sat.)	hot, cold
	R.F.		cold	hot				
Uranium,	O.F.			cold			hot	
	R.F.			hot, cold				
Vanadium,	O.F.						hot, cold	
	R.F.			cold		hot		

FLAMING.

Some substances yield a clear glass with borax or salt of phosphorus, which remains clear when cold, but at a certain point near saturation if heated slowly and gently or with an intermittent flame, or unequally, or by alternate oxidizing flame and reducing flame, the bead becomes opaque and enamel-like.

The reason is an incomplete fusion by which a part of the base is separated in the crystalline form.

Flaming is hindered or quite prevented by silica. The borax beads may in general be said to be colored more intensely by equal amounts of coloring oxides, than the salt of phosphorus beads while the latter may be said to yield the greater variety in color.

USE OF TIN WITH BEADS.

Reduction is sometimes assisted by transferring the borax or salt of phosphorus bead to charcoal and fusing it for a moment with a grain or two of metallic tin. The tin oxidizes and takes its oxygen partly from the oxides in the bead.

USE OF LEAD AND GOLD WITH BEADS.

Minute amounts of reduced metals, such as Cu, Ni, Co, may be collected from a bead by fusing it on charcoal with a small button of lead or gold. The glass bead can then be examined for the non-reducible oxides, and the lead or gold can by oxidation in contact with borax or salt of phosphorus, be made again to yield oxide colors from the reduced metals.

Separate the button and the slag, saving both, and heat the button with boracic acid to remove the lead, and then with frequently changed S. Ph. The metals which have united with the gold or lead will be successively oxidized, and their oxides will color the S. Ph. in the following order:

Co.—Blue, hot; blue, cold. May stay in the slag.

Ni.—Brown, hot; yellow, cold. May give green with Co or Cu.

Cu.—Green, hot; blue, cold. Made opaque red by tin and reducing flame.

The slag should contain the more easily oxidizable metals, and be free from Cu, Ni and Ag.

REDUCTION COLOR TESTS.

Saturate two S. Ph. beads with the substance in the oxidizing flame, treat one of them on charcoal with tin and strong reducing flame, pulverize and dissolve separately in cold dilute (1–4)

hydrochloric acid with the addition of a little tin. Let the solutions stand for some time and then heat them to boiling.

	The Oxidized Bead Yields		The Reduced Bead Yields	
	In Cold Solution.	In Hot Solution.	In Cold Solution.	In Hot Solution.
W.	Blue.	Deep Blue.	Deep Blue.	Deep Blue.
Mo.	Green to Blue.	Wine Brown.	Brown.	Faint Brown with Black Precipitate.
Ti.	Faint Violet.	Violet and Turbid.	Violet and Turbid.	Violet.
V.	Bluish Green.	Green.	Green.	Green.
Cr.	Green.	Green.	Green.	Green.
U.	Green.	Green.	Green.	Green.

Tests with Sodium Thiosulphate. $Na_2S_2O_3$.

A powdered metallic compound mixed with the dry flux, and either heated in a closed tube or upon a borax bead inside the blue flame will show the same color as would be produced by passing H_2S through a solution of the compound.

White = Zn. Orange = Sb. Yellow = Cd, As.

Brown = Sn, Mo. Green = Cr, Mn.

Black = Pb, Fe, Co, Cu, Ni, Ur, Bi, Ag, Au, Pt, Hg.

Use of Acids.

Acids are chiefly used in blowpipe work to expel and detect volatile constituents, to determine ease of solubility or to assist flame tests.

Volatile constituents are released with bubbling (effervescence), and the constituent is detected by the odor, or sometimes by passing the gas into another reagent. Generally a colorless, odorless gas shows the mineral to be a carbonate.

The mineral substance to be treated should be ground to fine powder, unless otherwise stated. Hydrochloric acid is commonly used but nitric acid is sometimes needed for metallic minerals.

Solubility may be:

With effervescence in the cold.

With effervescence only on heating.

Quiet and easy.

Difficult and incomplete.

With separation of perfect jelly.

With separation of imperfect jelly.
With separation of powder.
With separation of crystals.

Tests with Cobalt Solution.

Cobalt nitrate dissolved in ten parts of water is used to moisten light colored infusible substances. These are then heated to redness in the oxidizing flame and colored compounds result.

BLUE, Al_2O_3 and minerals containing it. Silicates of zinc.
GREEN (bluish), SnO_2.
GREEN (yellowish), ZnO, TiO_2.
GREEN (dark), oxides of antimony and columbium.
FLESH COLOR, MgO, and minerals containing it.

Test with Magnesium Ribbon.

Build a little pyramid of the powdered substance on charcoal, around a half inch length of magnesium ribbon and ignite the ribbon by touching with the flame; after the flash place in water.

Odor of $PH_3 = P$.

Tests with Acid Potassium Sulphate.

This reagent may be used to decompose insoluble compounds preparatory to wet separation, but its use in blowpipe analysis is chiefly to release volatile vapors and as a component of bismuth flux and boracic acid flux.

COLOR OF FUMES.	ODOR.	REMARKS.	INDICATING.
Brown.	Pungent.	From nitrates.	NO_2.
Brown.	Choking.	Turn starch paper yellow.	Br.
Violet.	Choking.	Turn starch paper violet.	I.
Yellowish-green.	Chlorine.	Explosive.	ClO_2.
Colorless.	Burning sulphur.	———	SO_2.
Colorless.	Pungent.	Corrodes the glass.	HF.
Colorless.	Chlorine.	White vapors with NH_3.	HCl.
Colorless.	Bad eggs.	Blacken lead acetate paper.	H_2S.
Colorless.	Almonds.	Whitens lime water.	HCN.
Colorless.	Odorless.	Whitens lime water.	CO_2.

Others of minor importance, acetic acid, chromic acid, organic acids, etc.

Tests with Potassium Chlorate.

Heat gradually in a matrass with the chlorate; finally there will be an energetic oxidation, and the fused mass will be:

Black = Ni, Cu. Bluish black = Co.

Purple = Mn. Brown = Pb. Flesh color = Fe.

Tests with Boracic Acid Flux.

Grind 4½ parts $KHSO_4$, 1 part CaF_2 to paste with water, add substance, thoroughly mixing. Heat at tip of the blue flame. Just after the water is driven off there may be yellow green flame of boron, or carmine flame of lithia.

Use of Boracic Acid.

Is used to separate lead and bismuth from antimony, copper, cadmium, silver, etc.

CHAPTER XII.

SUMMARY OF USEFUL TESTS WITH THE BLOWPIPE.

THE details of ordinary manipulations, such as obtaining beads, flames, coatings and sublimates, are omitted and the results alone stated; unusual manipulations are described. The bead tests are supposed to be obtained with oxides; the other tests are true, in general, of all compounds not expressly excluded. The course to be followed in the case of interfering elements is briefly stated.

ALUMINUM, Al.

With Soda.—Swells and forms an infusible compound.
With Borax or S. Ph.—Clear or cloudy, never opaque.
*With Cobalt Solution.**—Fine blue when cold.

AMMONIUM, NH_4.

In Closed Tube.—Evolution of gas with the characteristic odor. Soda or lime assists the reaction. The gas turns red litmus paper blue and forms white clouds with HCl vapor.

ANTIMONY, Sb.

On Coal, R. F.†—Volatile white coat, bluish in thin layers, continues to form after cessation of blast and appears to come directly off the mass.

With Bismuth Flux:

On Plaster.—Peach-red coat, somewhat mottled.

On Coal.—Faint yellow or red coat.

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* Certain phosphates, borates and fusible silicates become blue in absence of alumina.

† This coat may be further tested by S. Ph. or flame.

In Open Tube.—Dense, white, non-volatile, amorphous sublimate. The sulphide, too rapidly heated, will yield spots of red.

In Closed Tube.—The oxide will yield a white fusible sublimate of needle crystals, the sulphide, a black sublimate red when cold.

Flame.—Pale yellow-green.

With S. Ph.—Dissolved by O. F. and fused on coal with tin in R. F. becomes gray to black.

INTERFERING ELEMENTS.

Arsenic.—Remove by gentle O. F. on coal.

Arsenic with Sulphur.—Remove by gentle heating in closed tube.

Copper.—The S. Ph. bead with tin in R. F. may be momentarily red but will blacken.

Lead or Bismuth.—Retard formation of their coats by intermittent blast, or by adding boracic acid. Confirm coat by flame, not by S. Ph.

ARSENIC, As.

On Smoked Plaster.—White coat of octahedral crystals.

On Coal.—Very volatile white coat and strong garlic odor. The oxide and sulphide should be mixed with soda.

With Bismuth Flux:

On Plaster.—Reddish orange coat.

On Coal.—Faint yellow coat.

In Open Tube.—White sublimate of octahedral crystals. Too high heat may form deposit of red or yellow sulphide.

In Closed Tube.—May obtain white oxide, yellow or red sulphide, or black mirror of metal. If the tube is broken and the mirror heated, a strong garlic odor will be noticed.

Flame.—Pale azure blue.

INTERFERING ELEMENTS.

Antimony.—Heat in closed tube with soda and charcoal, break and treat resulting mirror in O. F. for odor.

Cobalt or Nickel.—Fuse in O. F. with lead and recognize by odor.

Sulphur.—(*a*) Red to yellow sublimate of sulphide of arsenic in closed tube.

(*b*) Odor when fused with soda on charcoal.

BARIUM, Ba.

On Coal with Soda.—Fuses and sinks into the coal.

Flame.—Yellowish green improved by moistening with HCl.

With Borax or S. Ph.—Clear and colorless, can be flamed opaque-white.

BISMUTH, Bi.

On Coal.—In either flame is reduced to brittle metal and yields a volatile coat, dark orange yellow hot, lemon yellow cold, with yellowish-white border.

*With Bismuth Flux:**

On Plaster.—Bright scarlet coat surrounded by chocolate brown, with sometimes a reddish border. The brown may be made red by ammonia.†

On Coal.—Bright red coat with sometimes an inner fringe of yellow.

With S. Ph.—Dissolved by O. F. and treated on coal with tin in R. F. is colorless hot but blackish gray and opaque cold.

INTERFERING ELEMENTS.

Antimony.—Treat on coal with boracic acid, and treat the resulting slag on plaster with bismuth flux.

Lead.—Dissolve coat in S. Ph. as above.

BORON, B.

All borates intumesce and fuse to a bead.

Flame.—Yellowish green. May be assisted by: (*a*) Moistening with H_2SO_4; (*b*) Mixing to paste with water, and boracic acid flux (4½ pts. $KHSO_4$, 1 pt. CaF_2); (*c*) By mixing to paste with H_2SO_4 and NH_4F.

BROMINE, Br.

With S. Ph. Saturated With CuO.—Treated at tip of blue flame, the bead will be surrounded by green and blue flames.

In Matrass With $KHSO_4$.—Brown choking vapor.

INTERFERING ELEMENTS.

Silver.—The bromide melts in $KHSO_4$ and forms a blood-red globule which cools yellow and becomes green in the sunlight.

* Sulphur 2 parts, potassic iodide 1 part, potassic bisulphate 1 part.

† May be obtained by heating S. Ph. on the assay.

CADMIUM, Cd.

On Coal R. F.—Dark brown coat, greenish yellow in thin layers. Beyond the coat, at first part of operation, the coal shows a variegated tarnish.

On Smoked Plaster with Bismuth Flux.—White coat made orange by $(NH_4)_2S$.

With Borax or S. Ph.—O. F. clear yellow hot, colorless cold, can be flamed milk-white. The hot bead touched to $Na_2S_2O_3$ becomes yellow.

R. F. Becomes slowly colorless.

Interfering Elements.

Lead, Bismuth, Zinc.—Collect the coat, mix with charcoal dust and heat gently in a closed tube. Cadmium will yield either a reddish brown ring or a metallic mirror. Before collecting coat treat it with O. F. to remove arsenic.

CALCIUM, Ca.

On Coal with Soda.—Insoluble and not absorbed by the coal.

Flame.—Yellowish red improved by moistening with HCl.

With Borax or S. Ph.—Clear and colorless, can be flamed opaque.

CARBON DIOXIDE, CO_2.

With Nitric Acid.—Heat with water and then with dilute acid. CO_2 will be set free with effervescence. The escaping gas will render lime-water turbid.

With Borax or S. Ph.—After the flux has been fused to a clear bead, the addition of a carbonate will cause effervescence during further fusion.

CHLORINE, Cl.

With S. Ph. Saturated with CuO.—Treated at tip of blue flame, the bead will be surrounded by an intense azure-blue flame.

On Coal with CuO.—Grind with a drop of H_2SO_4, spread the paste on coal, dry gently in O. F. and treat with blue flame, which will be colored greenish-blue and then azure-blue.

CHROMIUM, Cr.

With Borax or S. Ph.—O. F. Reddish hot, fine yellow-green cold.

R. F. In borax, green hot and cold. In S. Ph. red hot, green cold.

With Soda.—O. F. Dark yellow hot, opaque and light yellow cold.

R. F. Opaque and yellowish-green cold.

INTERFERING ELEMENTS.

Manganese.—The soda bead in O. F. will be bright yellowish-green.

COBALT, Co.

On Coal, R. F.—The oxide becomes magnetic metal. The solution in HCl will be rose-red but on evaporation will be blue.

With Borax or S. Ph.—Pure blue in either flame.

INTERFERING ELEMENTS.

Arsenic.—Roast and scorify with successive additions of borax. There may be, in order given: Yellow (iron), green (iron and cobalt), blue (cobalt), reddish-brown (nickel), green (nickel and copper), blue (copper).

Copper and other Elements which Color Strongly.—Fuse with borax and lead on coal in R. F. The borax on platinum wire in O. F. will show the cobalt, except when obscured by much iron or chromium.

Iron, Nickel or Chromium.—Fuse in R. F. with a little metallic arsenic, then treat as an arsenide.

Sulphur or Selenium.—Roast and scorify with borax, as before described.

COPPER, Cu.

On Coal R. F.—Formation of red malleable metal.

*Flame.**—Emerald-green or azure-blue, according to compound. The azure-blue flame may be obtained:

(*a*) By moistening with HCl or aqua regia, drying gently in O. F. and heating strongly in R. F.

(*b*) By saturating S. Ph. bead with substance, adding common salt, and treating with blue flame.

With Borax† *or S. Ph.*—O. F. Green hot, blue or greenish-blue cold.

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* Sulphur, selenium and arsenic should be removed by roasting. Lead necessitates a gentle heat.

† By repeated slow oxidation and reduction, a borax bead becomes ruby red.

R. F. Greenish or colorless hot, opaque and brownish-red cold. With tin on coal this reaction is more delicate.

INTERFERING ELEMENTS.

*General Method.**—Roast thoroughly, treat with borax on coal in strong R. F., and

If Button Forms.—Separate the button from the slag, remove any lead from it by O. F., and make either S. Ph. or flame test upon residual button.

If no Visible Button Forms.—Add test lead to the borax fusion, continue the reduction, separate the button and treat as in next test. (Lead Alloy.)

Lead or Bismuth Alloys.—Treat with frequently changed boracic acid in strong R. F., noting the appearance of slag and residual button.

Trace.—A red spot in the slag.

Over One Per Cent.—The residual button will be bluish-green when melted, will dissolve in the slag and color it red upon application of the O. F., or may be removed from the slag and be submitted to either the S. Ph. or the flame test.

FLUORINE, F.

Etching Test.—If fluorine is released it will corrode glass in cloudy patches, and in presence of silica there will be a deposit on the glass. According to the refractoriness of the compound the fluorine may be released:

(*a*) In closed tube by heat.

(*b*) In closed tube by heat and $KHSO_4$

(*c*) In open tube by heat and glass of S. Ph.

With Conc. H_2SO_4 *and* SiO_2.—If heated and the fumes condensed by a drop of water upon a platinum wire, a film of silicic acid will form upon the water.

IODINE, I.

With S. Ph. Saturated with CuO.—Treated at the tip of the blue flame the bead is surrounded by an intense emerald-green flame.

In Matrass with $KHSO_4$.—Violet choking vapor and brown sublimate.

* Oxides, sulphides, sulphates are best reduced by a mixture of soda and borax.

In Open Tube with Equal Parts Bismuth Oxide, Sulphur and Soda.—A brick-red sublimate.

With Starch Paper.—The vapor turns the paper dark purple.

INTERFERING ELEMENTS.

Silver.—The iodide melts in $KHSO_4$ to a dark red globule, yellow on cooling, and unchanged by sunlight.

IRON, Fe.

On Coal.—R. F. Many compounds become magnetic. Soda assists the reaction.

*With Borax.**—O. F. Yellow to red hot, colorless to yellow cold.
R. F. Bottle-green. With tin on coal, vitriol-green.

With S. Ph.—O. F. Yellow to red hot, greenish while cooling, colorless to yellow cold.
R. F. Red hot and cold, greenish while cooling.

State of the Iron.—A borax bead blue from CuO is made red by FeO, and greenish by Fe_2O_3.

INTERFERING ELEMENTS.

Chromium.—Fuse with nitrate and carbonate of soda on platinum, dissolve in water and test residue for iron.

Cobalt.—By dilution the blue of cobalt in borax may often be lost before the yellow of iron.

Copper.—May be removed from borax bead by fusion with lead on coal in R. F.

Manganese.—(*a*) May be faded from borax bead by treatment with tin on coal in R. F.
(*b*) May be faded from S. Ph. bead by R. F.

Nickel.—May be faded from borax bead by R. F.

Tungsten or Titanium.—The S. Ph. bead in R. F. will be reddish-brown instead of blue or violet.

Uranium.—As with chromium.

Alloys, Sulphides, Arsenides, etc.—Roast, treat with borax on coal in R. F., then treat borax in R. F. to remove reducible metals.

LEAD, Pb.

On Coal.†—In either flame is reduced to malleable metal and

* A slight yellow color can only be attributed to iron, when there is no decided color produced by either flame in highly charged beads of borax and S. Ph.

† The phosphate yields no coat without the aid of a flux.

yields, near the assay, a dark lemon-yellow coat, sulphur-yellow cold and bluish-white at border.

With Bismuth Flux:

On Plaster.—Chrome-yellow coat, blackened by $(NH_4)_2S$.

On Coal.—Volatile yellow coat, darker hot.

Flame.—Azure-blue.

With Borax or S. Ph.—O. F. Yellow hot, colorless cold, flames opaque-yellow.

R. F. Borax bead becomes clear, S. Ph. bead cloudy.

INTERFERING ELEMENTS.

Antimony.—Treat on coal with boracic acid, and treat the resulting slag on plaster with bismuth flux.

Arsenic Sulphide.—Remove by gentle O. F.

Cadmium.—Remove by R. F.

Bismuth.—Usually the bismuth flux tests on plaster are sufficient. In addition the lead coat should color the R. F. blue.

LITHIUM, Li.

Flame,—Crimson, best obtained by gently heating near the wick.

INTERFERING ELEMENTS.

Sodium, (*a*) Use a gentle flame and heat near the wick. (*b*) Fuse on platinum wire with barium chloride in O. F. The flame will be first strong yellow, then green, and lastly, crimson.

Calcium or Strontium.—As these elements do not color the flame in the presence of barium chloride, the above test will answer.

Silicon.—Make into a paste with boracic acid flux and water, and fuse in the blue flame. Just after the flux fuses the red flame will appear.

MAGNESIUM, Mg.

On Coal with Soda.—Insoluble, and not absorbed by the coal.

With Borax or S. Ph.—Clear and colorless can be flamed opaque-white.

*With Cobalt Solution.**—Strongly heated becomes a pale flesh color.

MANGANESE, Mn.

With Borax or S. Ph.†—O. F. Amethystine hot, reddens on cool-

* With silicates this reaction is of use only in the absence of coloring oxides. The phosphate, arsenate and borate become violet-red.

† The colors are more intense with borax than with S. Ph.

ing. With much, is black and opaque. If a hot bead is touched to a crystal of sodium nitrate an amethystine or rose-colored froth is formed.

R. F. Colorless or with black spots.

With Soda.—O. F. Bluish-green and opaque when cold. Sodium nitrate assists the reaction.

INTERFERING ELEMENTS.

Chromium.—The soda bead in O. F. will be bright yellowish-green instead of bluish-green.

Silicon.—Dissolve in borax, then make soda fusion.

MERCURY, Hg.

With Bismuth Flux:

On Plaster.—Volatile yellow and scarlet coat. If too strongly heated the coat is black and yellow.

On Coal.—Faint yellow coat at a distance.

*In Matrass with Dry Soda or with Litharge.**—Mirror-like sublimate, which may be collected in globules.

MOLYBDENUM, Mo.

On Coal.—O. F. A coat yellowish hot, white cold, crystalline near assay.

R. F. The coat is turned in part deep blue, in part dark copper-red.

Flame.—Yellowish-green.

With Borax.—O. F. Yellow hot, colorless cold.

R. F. Brown to black and opaque.

With S. Ph.—O. F. Yellowish-green hot, colorless cold.†

R. F. Emerald-green.

Dilute ($\frac{1}{4}$) *HCl Solutions.*—If insoluble the substance may first be fused with S. Ph. in O. F. If then dissolved in the acid and heated with metallic tin, zinc or copper, the solutions will be successively blue, green and brown. If the S. Ph. bead has been treated in R. F. the solution will become brown.

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* Gold-leaf is whitened by the slightest trace of vapor of mercury.

† Crushed between damp unglazed paper becomes red, brown, purple or blue, according to amount present.

NICKEL, Ni.

On Coal.—R. F. The oxide becomes magnetic.

With Borax.—O. F. Violet hot, pale reddish-brown cold.

R. F. Cloudy and finally clear and colorless.

With S. Ph.—O. F. Red hot, yellow cold.

R. F. Red hot, yellow cold. On coal with tin becomes colorless.

INTERFERING ELEMENTS.

General Method.—Saturate two or three borax beads with roasted substance, and treat on coal with a strong R. F. If a visible button results, separate it from the borax, and treat with S. Ph. in the O. F., replacing the S. Ph. when a color is obtained.

If no visible button results, add either a small gold button or a few grains of test lead. Continue the reduction, and :

With Gold.—Treat the gold alloy on coal with S. Ph. in strong O. F.

With Lead.—Scorify button with boracic acid to small size, complete the removal of lead by O. F. on coal, and treat residual button with S. Ph. in O. F.

Arsenic.—Roast thoroughly, treat with borax in R. F. as long as it shows color, treat residual button with S. Ph. in O. F.

Alloys.—Roast and melt with frequently changed borax in R. F. adding a little lead if infusible. When the borax is no longer colored, treat residual button with S. Ph. in O. F.

NITRIC ACID, HNO_3.

In Matrass with $KHSO_4$, or in Closed Tube with Litharge.—Brown fumes with characteristic odor. The fumes will turn ferrous sulphate paper brown.

PHOSPHORUS. P.

Flame.—Greenish-blue, momentary. Improved by conc. H_2SO_4.

In Closed Tube with Dry Soda and Magnesium.—The soda and substance are mixed in equal parts and dried, and made to cover the magnesium. Upon strongly heating there will be a vivid incandescence, and the resulting mass, crushed and moistened, will yield the odor of phosphuretted hydrogen.

POTASSIUM, K.

Flame.—Violet, except borates and phosphates.

INTERFERING ELEMENTS.

Sodium.—(*a*) The flame, through blue glass, will be violet or blue.

(*b*) A bead of borax and a little boracic acid, made brown by nickel, will become blue on addition of a potassium compound.

Lithium.—The flame, through green glass, will be bluish-green.

SELENIUM, Se.

On Coal, R. F.—Disagreeable horse-radish odor, brown fumes, and a volatile steel-gray coat with a red border.

In Open Tube.—Steel-gray sublimate, with red border, sometimes white crystals.

In Closed Tube.—Dark-red sublimate and horse-radish odor.

Flame.—Azure-blue.

On Coal with Soda.—Thoroughly fuse in R. F., place on bright silver, moisten, crush, and let stand. The silver will be blackened.

SILICON, Si.

On Cool with Soda.—With its own volume of soda, dissolves with effervescence to a clear bead. With more soda the bead is opaque.

With Borax.—Clear and colorless.

With S. Ph.—Insoluble. The test made upon a small fragment will usually show a translucent mass of undissolved matter of the shape of the original fragment.

When not decomposed by S. Ph., dissolve in borax nearly to saturation, add S. Ph., and re-heat for a moment. The bead will become milky or opaque white.

SILVER, Ag.

On Coal.—Reduction to malleable white metal.

With Borax or S. Ph.—O. F. Opalescent.

Cupellation.—Fuse on coal with 1 vol. of borax glass and 1 to 2 vols. of test lead in R. F. for about two minutes. Remove button and scorify it in R. F. with fresh borax, then place button on cupel and blow O. F. *across* it, using as strong blast and as little flame as are consistent with keeping button melted.

If the litharge is dark, or if the button freezes before brightening, or if it brightens but is not spherical, rescorify it on coal with borax,

add more test lead, and again cupel until there remains only a white spherical button of silver.

SODIUM, Na.

Flame.—Strong reddish-yellow.

STRONTIUM, Sr.

On Coal with Soda.—Insoluble, absorbed by the coal.

Flame.—Intense crimson, improved by moistening with HCl.

With Borax or S. Ph.—Clear and colorless; can be flamed opaque.

INTERFERING ELEMENTS.

Barium.—The red flame may show upon first introduction of the sample into the flame, but it is afterward turned brownish-yellow.

Lithium.—Fuse with barium chloride, by which the lithium flame is unchanged.

SULPHUR, S.

On Coal with Soda and a Little Borax.—Thoroughly fuse in the R. F., and either:

(*a*) Place on bright silver, moisten, crush and let stand. The silver will become brown to black. Or,

(*b*) Heat with dilute HCl (sometimes with powdered zinc); the odor of H_2S will be observed.

In Open Tube.—Suffocating fumes. Some sulphates are unaffected.

In Closed Tube.—May have sublimate red when hot, yellow cold, or sublimate of undecomposed sulphide, or the substance may be unaffected.

With Soda and Silica (equal parts).—A yellow or red bead.

To Determine Whether Sulphide or Sulphate.—Fuse with soda on platinum foil. The sulphide only will stain silver.

TELLURIUM, Te.

On Coal.—Volatile white coat with red or yellow border. If the fumes are caught on porcelain, the resulting gray or brown film may be turned crimson when moistened with conc. H_2SO_4, and gently heated.

On Coal with Soda.—Thoroughly fuse in R. F. Place on bright silver, moisten, crush and let stand. The silver will be blackened.

Flame.—Green.

In Open Tube.—Gray sublimate fusible to clear drops.

With H_2SO_4 (conc.).—Boiled a moment, there results a purple violet solution, which loses its color on further heating or on dilution.

TIN, Sn.

On Coal.—O. F. The oxide becomes yellow and luminous.

R. F. A slight coat, assisted by addition of sulphur or soda.

With Cobalt Solution.—Moisten the coal, in front of the assay, with the solution, and blow a *strong* R. F. upon the assay. The coat will be bluish-green when cold.

With CuO in Borax Bead.—A faint blue bead is made reddish-brown or ruby-red by heating a moment in R. F. with a tin compound.

INTERFERING ELEMENTS.

Lead or Bismuth (Alloys).—It is fair proof of tin if such an alloy oxidizes rapidly with sprouting and cannot be kept fused.

Zinc.—On coal with soda, borax and charcoal in R. F. the tin will be reduced, the zinc volatilized; the tin may then be washed from the fused mass.

TITANIUM,* Ti.

With Borax.—O. F. Colorless to yellow hot, colorless cold, opalescent or opaque-white by flaming.

R. F. Yellow to brown, enamel blue by flaming.

With S. Ph.—O. F. As with borax.

R. F. Yellow hot, violet cold.

HCl Solutions.—If insoluble the substance may first be fused with S. Ph. or with soda and reduced. If then dissolved in dilute acid and heated with metallic tin, the solution will become violet after standing. Usually there will also be a turbid violet precipitate, which becomes white.

INTERFERING ELEMENTS.

Iron.—The S. Ph. bead in R. F. is yellow hot, brownish-red cold.

TUNGSTEN, W.

With Borax.—O. F. Colorless to yellow hot, colorless cold, can be flamed opaque-white.

* If the substance is mixed with sodium fluoride, fused on platinum with a little sodium pyrosulphate and dissolved by boiling in a very weak solution of sulphuric acid, the addition of a few drops of hydrogen peroxide will produce a color like that of ferric chloride.

R. F. Colorless to yellow hot, yellowish-brown cold.

With S. Ph.—O. F. Clear and colorless.

R. F. Greenish hot, blue cold. On long blowing or with tin on coal, becomes dark green.

With Dilute HCl.—If insoluble, the substance may first be fused with S. Ph. The solution heated with tin becomes dark blue; with zinc it becomes purple and then reddish-brown.

INTERFERING ELEMENTS.

Iron.—The S. Ph. in R. F. is yellow hot, blood-red cold.

URANIUM, U.

With Borax.—O. F. Yellow hot, colorless cold, can be flamed enamel yellow.

R. F. Bottle-green, can be flamed black but not enamelled.

With S. Ph.—O. F. Yellow hot, yellowish-green cold.

R. F. emerald-green.

INTERFERING ELEMENTS.

Iron.—With S. Ph. in R. F. is green hot, red cold.

VANADIUM, V.

With Borax.—O. F. Colorless or yellow hot, greenish-yellow

R. F. Brownish hot, emerald-green cold.

With S. Ph.—O. F. Dark yellow hot, light yellow cold.

R. F. Brown hot, emerald-green cold.

H_2SO_4 Solutions.—Reduced by Zn become successively yellow, green, bluish-green, blue, greenish-blue, bluish-violet and lavender.

ZINC, Zn.

On Coal.—O. F. The oxide becomes yellow and luminous.

R. F. Yellow coat, white when cold, assisted by soda and a little borax.

With Cobalt Solution.—Moisten the coal, in front of the assay, with the solution, and blow a strong R. F. upon the assay. The coat will be bright yellow-green when cold.

INTERFERING ELEMENTS.

Antimony.—Remove by strong O. F., or by heating with sulphur in closed tube.

Cadmium Lead or Bismuth.—The combined coats will not prevent the cobalt solution test.

Tin.—The coats heated in an open tube, with charcoal dust by the O. F., may yield white sublimate of zinc.

CHAPTER XIII.

SCHEMES FOR QUALITATIVE BLOWPIPE ANALYSIS.

TEST I.* — **Heat a portion gently with O. F. upon charcoal or a plaster tablet which has been blackened in the lamp flame.**

As. — White very volatile crystalline coat, white fumes having garlic odor and invisible near assay, best on plaster.

The coat disappears before R. F., tingeing it pale blue and evolving the characteristic garlic odor.

CONFIRMATION **As.** — The coating may be scraped off together with a little charcoal and if heated in closed tube should yield an arsenic mirror; or it may be dissolved in solution of KOH, placed in a test-tube, a small piece of sodium amalgam added, and the tube covered with a piece of filter paper moistened with a *slightly* acid solution of $AgNO_3$. The paper will be stained black by the AsH_3 evolved.

Sb. — White fumes and white pulverulent volatile coat, best on charcoal.

A good distinguishing feature between As and Sb is as follows: They both usually continue to give off fumes after removal of the flame, but while still hot the As_2O_3 fumes are not visible within one-half inch of assay, while Sb_2O_4 fumes appear to come immediately from the mass.

CONFIRMATION **Sb.** — The coating disappears before R. F., tingeing it a pale yellow-green, or, if scraped together, dissolved in S. Ph. and *just* fused on charcoal in contact with tin it will form a gray or black opaque bead.

If the coating be scraped off and dissolved in tartaric acid + HCl, and the solution placed in a platinum capsule with a piece of zinc, Sb, if present, will give a black adherent stain. This may be confirmed by washing the stain with water, then dissolving it in a few drops of hot tartaric acid plus a drop or two of HCl; on adding H_2S, an orange precipitate proves Sb_2S_3.

Most antimony minerals leave a white residue when treated with concentrated nitric acid. If this residue is washed with water, dissolved in HCl and H_2S added, an orange precipitate of Sb_2S_3 will be formed.

TEST II. — **Mix some of the powdered substance with metallic sodium† by means of a knife blade, ignite carefully on charcoal and heat residue with blowpipe flame to obtain coatings or to fuse together any metallic particles.‡ Or mix a portion with soda and**

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* Test I. may also yield white coating of chlorides or lead sulphate, or of Se or Te, non-volatile coatings of Sn or Zn near the assay, yellow hot and white cold; yellow coatings of Pb or Bi; crystalline yellow and white coating of Mo; and deep brown coating of Cd. All of these will be detected with greater certainty by later tests.

† Test II. may also yield white coats from Pb, Bi or alkalis, yellow coats from Pb or Bi, brown or red coats from Cu or Mo, and the ash of the coal may be white or red.

‡ Until perfectly familiar with metallic sodium reaction always read the precaution on page 92.

a little borax and heat strongly upon charcoal with R. F. for three or four minutes.

A. Volatile fumes or coating on charcoal.

As.—Garlic odor, white fumes and a white volatile coat.

Sb.—White fumes and a white volatile coat.

Cd.—Dark brown volatile coat, sometimes shading to greenish-yellow and usually surrounded by a variegated coloration resembling the colors of peacock feathers.

CONFIRMATION **Cd.**—The coat forms at first heating, and, if mixed with $Na_2S_2O_3$ and fused in a borax bead, will form a bright yellow mass of CdS.

Zn.—White not easily volatile coat, yellow when hot.

Sn.—White non-volatile coat close to assay, yellow while hot and usually small in amount.

CONFIRMATION **Zn** and **Sn.**—If any coat forms, moisten it with cobalt solution and blow a strong blue flame on the substance. The coatings from other elements will not prevent the cobalt coloration. The zinc coat is made bright yellowish-green. The tin coat becomes bluish-green.

B. Residue left on charcoal.

Crush, pulverize and examine the residue for

1. Magnetic particles; 2. Metallic buttons; 3. On moist silver coin.

1. Collect any magnetic particles with the magnet; dissolve some of the magnetic particles in a borax bead with the O. F. Try also effect of R. F.

Fe.—The bead is: O. F. hot, yellow to red; O. F. cold, colorless to yellow; R. F. cold, bottle-green.

CONFIRMATION **Fe.**—The magnetic particles yield with HNO_3, a brown solution from which, after evaporating excess of acid, K_4FeCy_6 throws down a blue precipitate.

Ni.—The bead is: O. F. hot, intense violet; O. F. cold, pale brown; R. F. cold, colorless.

CONFIRMATION **Ni.**—If the excess of acid is driven off by evaporation, KCy added in excess, and the solution then made strongly alkaline with KOH, two or three drops of pure bromine will give a black precipitate of $Ni_2(OH)_6$.

Co.—The bead is: O. F. and R. F. hot or cold, a deep pure blue; if greenish when hot, probably Fe or Ni is also present.

CONFIRMATION **Co.**—The magnetic particles yield with HNO_3, a red-rose solution which becomes blue on evaporation.

2. Examine residue for metallic buttons and observe if they are malleable or not.*

Ag. — Silver white malleable button.

CONFIRMATION **Ag.** — Dissolve button in dilute HNO_3, and add a drop of HCl. A white precipitate, soluble in NH_4OH is obtained.

Pb. — Lead gray malleable button.

CONFIRMATION **Pb.** — With bismuth flux on charcoal gives yellow coating.

Sn. — White malleable button.

CONFIRMATION **Sn.** — Heated in O. F. on charcoal gives a non-volatile coating, yellow hot and white cold. Decomposed in conc. HNO_3 with white residue of metastannic acid.

Cu. — Reddish malleable button.

CONFIRMATION **Cu.** — Dissolves in HNO_3 to a green solution rendered intense blue when neutralized with NH_4OH.

Au. — Yellow malleable button.

CONFIRMATION **Au.** — Insoluble in HNO_3 or HCl alone, but dissolved by mixed acids.

Bi. — Reddish white brittle button.

CONFIRMATION **Bi.** — Heat with bismuth flux.

Sb. — White brittle button, yielding white coating before the blowpipe.

3. Dig up some of the charcoal beneath assay, place upon a bright silver surface; moisten with water and let stand.

S, Se, Te.—The bright silver is stained black or dark-brown, and unless the horseradish odor of Se or the brown coatings of Se and Te with bismuth flux have been already obtained, this stain will prove sulphur.

CONFIRMATIONS **S.**—The soda fusion will evolve H_2S when moistened with HCl. By holding in the gas a piece of filter paper moistened with a drop or two of lead acetate (test is made more sensitive by adding a drop of ammonia to the acetate), the paper will be stained black.

CONFIRMATION **Se.**—Characteristic disagreeable horseradish odor during fusion.

CONFIRMATIONS **Te.**—If a little of the original substance is dropped into boiling concentrated H_2SO_4, a deep violet color is produced; this disappears on further heating.

The quite cold soda fusion added to hot water produces a purple-red solution.

TEST III.—**Mix a portion of the substance with more than an equal volume of bismuth flux,† and heat gently upon a plaster tablet with the oxidizing flame.**

* A white malleable button of zinc is sometimes obtained but not if reduction was made by soda. It is easily soluble in cold dilute hydrochloric acid with effervescence.

† Formed by grinding together 1 part KI, 1 part $KHSO_4$, 2 parts S.

Pb.—Chrome-yellow coat, darker hot, often covering the entire tablet.

CONFIRMATION **Pb.**—If the test is made on charcoal, the coat is greenish-yellow, brown near the assay.

Hg.—Gently heated, bright scarlet coat, very volatile, and with yellow fringe; but if quickly heated, the coat formed is pale yellow and black.

CONFIRMATION **Hg.**—If the substance is heated gently in a closed tube or matrass with dry soda or litharge, a mirror-like sublimate will form, which may be collected into little globules of Hg by rubbing with a match end. The test with bismuth flux on charcoal yields only a faint yellow coat.

Bi.—Bright chocolate-brown coat, with sometimes a reddish fringe.

CONFIRMATIONS **Bi.**—The coat is turned orange-yellow, then cherry-red, by fumes of NH_3, which may conveniently be produced by heating a few crystals of S. Ph. on the assay. The test with bismuth flux on charcoal yields a bright-red band, with sometimes an inner fringe of yellow.

Sb.—Orange to peach-red coat, very dark when hot.

CONFIRMATION **Sb.**—The coat becomes orange when moistened with $(NH_4)_2S$.

Test IV. may yield colored sublimates with large amounts of certain other elements, and on smoked plaster certain white sublimates are obtainable. In all cases the elements are detected with greater certainty by other tests, but for convenience they are here summarized: Sn, brownish-orange; As, reddish-orange; Se, reddish-brown; Te, purplish-brown, with deep brown border; Mo, deep ultramarine blue; Cu, Cd, Zn, white on smoked plaster.

TEST IV.—**Dissolve substance in salt of phosphorus in O. F. so long as bead remains clear on cooling. Treat then for three or four minutes in a strong R. F. to remove volatile compounds. Note the colors hot and cold, then re-oxidize and note colors hot and cold.**

Fe, Ti, Mo, W.—The bead in O. F. cold is COLORLESS or very FAINT YELLOW.

CONFIRMATION **Fe.**—The bead in its previous treatment should have been O. F. hot, yellow to red; O. F. cold, colorless; R. F. cold, bottle green.

CONFIRMATION **Ti.**—The bead is reduced on charcoal with tin, pulverized and dissolved in $\frac{1}{4}$ HCl with a little metallic tin. The reduced bead is violet, the solution is violet and turbid.

CONFIRMATIONS **Mo.**—Tested as above on charcoal with tin, etc., the reduced bead is green, the solution is dark brown. Heat a little of the substance on platinum foil with a few drops of conc. HNO_3, heat until excess of HNO_3 has all volatilized, then add

few drops of strong H_2SO_4 and heat until copious fumes are evolved; cool, and breathe upon the cooled mass; an ultramarine blue = Mo.

CONFIRMATION W.—Tested on charcoal with tin, etc., as above, the reduced bead is green, the solution is deep blue.

Ur, V, Ni.*—The bead in O. F. cold, is colored YELLOW OR GREENISH-YELLOW.

CONFIRMATION U.—The bead in R. F. is dull green, hot; fine green, cold. Make a Na_2CO_3 fusion, dissolve in HCl or H_2SO_4, add a few drops or H_2S water, and if it gives any precipitate, add it in excess and filter; to filtrate add a few drops of HNO_3 and boil, then add NH_4OH to alkaline reaction, filter, wash precipitate with ammonia water, and then treat precipitate with a concentrated solution of $(NH_4)_2CO_3 + NH_4OH$, filter, acidify filtrate with HCl, and add K_4FeCy_6. Brown ppt. = Ur.

CONFIRMATION V.—In R. F. the bead will be brownish hot, fine green cold. Fuse substance with Na_2CO_3 in O. F., and dissolve fusion in a few drops of dilute H_2SO_4 or HCl, add a piece of zinc and warm; blue color changing to green and finally violet = V.

CONFIRMATION Ni.—A borax bead in O. F. will be intense violet, and in R. F. will be reddish hot, yellow cold.

Mn.—The bead in O. F., cold, is colored VIOLET; if touched while hot to a crystal of nitre, it is made deep permanganate color.

CONFIRMATION Mn.—Fused on platinum wire in O. F., with a paste of soda, and nitre, manganese yields an opaque bluish-green bead.

Cr.—The bead in O. F., cold, is colored GREEN.

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* If the absence of Ni is not proved, or Co obscures the tests, dissolve the substance in borax on charcoal to saturation, and treat for five minutes in hot R. F.

If a visible button results, separate it from the borax, and treat with S. Ph. in the O. F., replacing the S. Ph. when a color is obtained.

If no visible button results, add either a small gold button or a few grains of test lead. Continue the reduction, and, if lead has been used, scorify the button with frequently changed boracic acid to small size, stopping the instant the boracic acid is colored by Co, Ni, or Cu, blue, yellow, or red, respectively.

Complete the removal of lead by O. F. on coal, and treat as below.

Treat the gold alloy, or the residual button from the lead alloy, on coal, with frequently changed S. Ph., in strong O. F.

The metals which have united with the gold or lead, will be successively oxidized and their oxides will color the S. Ph. in the following order:

Co.—Blue, hot; blue, cold. May stay in the slag.

Ni.—Brown, hot; yellow, cold. May give green with Co or Cu.

Cu.—Green, hot; blue, cold. Made opaque red by tin and R. F.

The slag should contain the more easily oxidizable metals, and be free from Cu, Ni, and Ag. Test a portion with S. Ph. and tin to prove absence of Cu. If present, it must be removed by further reduction with lead. Pulverize the slags and dissolve a portion in S. Ph., and examine by Test V.

There may be a green bead from admixture of a blue and a yellow. If Cr is not proved, examine in such a case for Ur, V, Cr, etc., with unusual care.

CONFIRMATION **Cr.**—If the substance is fused on platinum wire in the O.F. with a paste of soda and nitre, an opaque yellow bead is produced; and if the soda bead is dissolved in water, filtered, acidified with acetic acid, and a drop or two of lead acetate added, a yellow precipitate will be formed.

Co, Cu.—The bead in O. F., cold, is colored BLUE.

CONFIRMATION **Co.**—The bead is deep blue, hot and cold, in both flames.

CONFIRMATION **Cu.**—The bead is green, hot, greenish-blue, cold, and on fusion with tin on coal becomes opaque brownish-red.

With larger percentage of copper, the substance will yield a mixed azure-blue and green flame on heating with HCl.

SiO_2, Al_2O_3, TiO_2, SnO_2.—The saturated bead contains an appreciable amount of INSOLUBLE MATERIAL, in the form of a *translucent* cloud, jelly-like mass, or skeleton form of the original material.

CONFIRMATION **SiO_2.**—Mix the *dry* substance with a little *dry* calcium fluoride free from SiO_2, place in a *dry* test tube and add conc. H_2SO_4 and heat gently, hold in fumes given off, a drop of water in loop of platinum wire; SiO_2 will be separated on coming in contact with the water and form a jelly-like mass.

Silica or silicates fused with soda unite with noticeable effervescence.

CONFIRMATION **Al_2O_3, TiO_2, SnO_2, SiO_2.**—If infusible, moisten the pulverized mineral with dilute cobalt nitrate solution and heat strongly.

Al_2O_3.—Beautiful bright blue.

TiO_2.—Yellowish green.

SnO_2 —Bluish green.

SiO_2.—Faint blue; deep blue, if fusible.

There may also be blues from fusible phosphates and borates, greens from oxides of Zn, Sb, violet from Zr, various indefinite browns and grays, and a very characteristic pale pink or flesh color from Mg.

CONFIRMATION **SnO_2.**—Treat the finely pulverized mineral with Zn and HCl in contact with platinum. Dissolve any reduced metal in HCl and test with $HgCl_2$. There will be white or gray ppt.

Ba, Ca, Sr, Mg.—The saturated bead is WHITE and OPAQUE and the nearly saturated bead can be flamed white and opaque.

CONFIRMATION **Ba, Ca, Sr.**—Moisten the flattened end of a clean platinum wire with dilute hydrochloric acid, dip it in the roasted substance, and heat strongly at the tip of the blue flame, and gently near the wick. Remoisten with the acid frequently.

Ba.—Yellowish-green flame, bluish-green through green glass.

Ca.—Yellowish-red (brick-red) flame, green through green glass.

Sr.—Scarlet-red flame, faint yellow through green glass.

There may also be produced **Li**, carmine-red flame, invisible through green glass.

K, rose-violet flame, reddish-violet through blue glass. **Na**, orange-yellow flame, invisible through blue glass. **Cu.** azure-blue and emerald green. **Se** and **As**, pale blue. **Mo, Sb, Te**, pale green.

CONFIRMATION **Mg.**—Moisten the roasted substance with cobalt solution, and heat strongly. The substance will be colored pale pink or flesh color, or violet if present as either arsenate or phosphate or borate.

TEST V.—**Cupellation for silver and gold. Fuse one vol. of the roasted substance on charcoal with 1 vol. of borax glass, and 1 to 2 vols. of test lead in R. F. for about two minutes. Remove button and scorify it in R F. with fresh borax, then place button on cupel and blow O. F.** ***across*** **it, using as strong blast and as little flame as are consistent with keeping the button melted. If the litharge is dark, or if the button freezes before brightening, or if it brightens but is not spherical, re-scorify it on charcoal with borax, add more test lead, and again cupel until there remains only a bright spherical button unaltered by further blowing.**

Ag.—The button is white.
Au.—The button is yellow or white.

CONFIRMATION **Ag** AND **Au.**—Dissolve in a drop of HNO_3, and add a drop of HCl, producing a white curd-like precipitate. If gold is present there will be a residue insoluble in HNO_3 which will become golden yellow on ignition.

TEST VI.—**Heat substance in matrass with acid potassium sulphate.**

N_2O_5, Br.—Reddish brown vapor.

CONFIRMATION **N_2O_5.**—The gas turns ferrous sulphate paper brown. Nitrates deflagrate violently when fused on charcoal.

Cl.—Colorless or yellowish green vapor, with odor of chlorine.
I.—Violet choking vapor.

CONFIRMATION **Br, Cl, I.**—Saturate a salt of phosphorus bead with CuO, add substance, and treat in O. F. Br, azure blue and emerald green flame. Cl, azure blue flame with a little green. I, emerald green flame.

Fuse with Na_2CO_3, pulverize and mix with MnO_2, and add a few drops of conc. H_2SO_4, and heat. Cl, yellowish green gas that bleaches vegetable colors. Br, red fumes.

Fuse with Na_2CO_3, dissolve in water, make slightly acid with H_2SO_4, and add $Fe_2(SO_4)_3$ (ferric alum may be used), and boil; I, violet fumes (turn starch paper blue).

F.—The glass of the matrass is corroded, and if SiO_2 is present a film of SiO_2 is often deposited on the glass.

CONFIRMATION **F.**—If the substance be mixed with silica and then heated with concentrated sulphuric acid, and the fumes caught on a drop of water held in a loop of platinum wire, gelatinous silica will form in the water.

TEST VII.—**Heat the substance gently with water to remove air bubbles and then with dilute hydrochloric acid.**

CO_2.—Effervescence continuing after heat is removed.

H_2S, Cl and H are sometimes evolved, but usually the odor will distinguish these.

CONFIRMATION **CO_2.**—If the gas is passed into lime water, a white cloud and ppt. will be produced.

TEST VIII.—**Place a piece of Mg wire in a closed tube, and cover the wire with a mixture of soda and the substance. Heat till the mass takes fire, cool and add water.**

P.—Evolution of phosphine, recognized by odor.

CONFIRMATION **P.**—Fuse a little of the substance, previously roasted if it contains As, with two or three parts Na_2CO_3 and one of $NaNO_3$ dissolve in HNO_3, and add excess of $(NH_4)_2MoO_4$; yellow ppt. $= P_2O_5$. In presence of SiO_2 it is well to confirm this ppt. by dissolving it in dilute NH_4OH, allowing it to stand for half an hour and filtering off any SiO_2 that separates, then to filtrate adding magnesia mixture ($MgCl_2 + NH_4Cl + NH_4OH$); white ppt. $= P_2O_5$.

Phosphates yield a pale momentary bluish green flame when moistened with concentrated H_2SO_4 and treated at the tip of the blue flame.

TEST IX.—**Make a paste of four parts $KHSO_4$, one part CaF_2, water and substance. Treat at tip of blue flame. Just after water is driven off the flame will be colored.**

B.—Bright green.

Li.—Carmine.

CONFIRMATION **B.** — Heat some of the substance gently on platinum wire, then add a drop of concentrated H_2SO_4, heat very gently again, just enough to drive off exces of H_2SO_4, dip in glycerine, hold in flame until glycerine begins to burn, remove from flame, and the mass will continue burning with a green flame. Turmeric paper, moistened with an HCl solution containing boron and dried at 100°, is turned a reddish brown which ammonia blackens.

TEST X.—**Make a paste of the powdered substance with strong HCl. Treat on platinum wire in the non-luminous flame of a Bunsen burner. Confirm results by the spectroscope as directed on page 87.**

The color imparted to the flame is:

	Alone.	*Through blue glass.*
Na,	Yellow.	Invisible or pale blue.
K,	Violet.	Reddish violet.
Na and K,	Yellow.	Reddish violet.
Ba, Mo, B,	Yellowish green.	Bluish green.
Ca,	Red.	Greenish gray.
Sr,	Scarlet.	Violet.
Cu,	Azure blue, Emerald green.	Azure blue. Emerald green.

TEST XI. — **Heat the substance in a closed tube.***

H_2O. — Moisture on the side of tube.
Hg. — Metallic mirror collecting in globules.
As. — Metallic mirror but no globules.

TEST XII.† — **Treat the finely powdered substance in a test-tube with strong HCl. Observe the result, then boil.**

Effervescence. — If the substance is non-metallic the gas given off will almost always be CO_2 showing that the substance was a carbonate. H_2S is easily recognized by its odor. Cl which is yellowish and very offensive would be given off only in a few cases by the action of some oxides on HCl.

CONFIRMATION **CO_2.** — A drop of lime water on the end of a glass rod held in the gas after it has been passed through water to free it from HCl will be rendered turbid.

CONFIRMATION **H_2S.** — A piece of filter paper moistened with lead acetate will be blackened if held in the gas.

CONFIRMATION **Cl.** — A piece of moistened red litmus paper held in the gas will be bleached.

Gelatinous Residue. — If a gelatinous residue forms after boiling away the larger part of the acid a silicate was present.

* Other sublimates may result as noted on page 94.

† Substitute for test VII. when convenient.

SPECIAL SCHEME FOR DETECTION OF THOSE METALS WHICH WHEN PRESENT AS SILICATES USUALLY FAIL TO YIELD SATISFACTORY TESTS BEFORE THE BLOWPIPE.

Remove the volatile constituents as thoroughly as possible by roasting, then heat gently in a platinum capsule, with HF and a few drops of concentrated H_2SO_4 as long as fumes are given off; add a little more HF and H_2SO_4, and heat again in the same way. When fusion is quite cold, dissolve in cold water and filter.

Filtrate a.—Divide into four parts and test as follows:

1. Add a piece of Zn or Sn and a little HCl, and heat.

Ti.—A violet or blue solution.

CONFIRMATIONS **Ti.**—Nearly neutralize solution, and then add $Na_2S_2O_3$, and boil. White ppt. = Ti.

Or, make solution slightly alkaline, and then acidify slightly with HCl, and add Na_2HPO_4. White ppt. = Ti.

2. Add excess of KOH or NaOH, boil and filter, and to filtrate add excess of NH_4Cl. and boil.

Al.—White precipitate.

Dissolve ppt., produced by the KOH or NaOH, in HCl, and add K_4FeCy_6.

Fe.—Blue precipitate.

3. Add HCl; then make alkaline with NH_4OH and add $(NH_4)_2S$ + $(NH_4)_2CO_3$ in slight excess, filter; to filtrate add Na_2HPO_4.

Mg.—White *crystalline* precipitate.

CONFIRMATION **Mg.**—If phosphates are present, this test would not be reliable for Mg. In such cases test a few drops of the solution with H_2S; if it causes any precipitate, saturate the whole of the solution with it, filter, and to filtrate add a few drops of HNO_3, and boil to oxidize FeO, nearly neutralize with solution of Na_2CO_3. If iron is not present, add a few drops of Fe_2Cl_6, enough to give a red precipitate with the sodium acetate, then dilute and add excess of sodium acetate, and boil, filter, and to filtrate add NH_4OH + $(NH_4)_2S$, filter, to filtrate add Na_2HPO_4. White crystalline precipitate = Mg.

4. Add $BaCl_2$ as long as it gives a precipitate, then $Ba(OH)_2$ to alkaline reaction, boil, filter, and to filtrate add $(NH_4)_2CO_3$ and NH_4OH and heat, filter; evaporate filtrate to dryness and ignite to drive out NH_4 salts. Test residue in flame for K and Na; dissolve residue in a few drops of water, filter if necessary, and then add solution of $PtCl_4$ and alcohol.

K. — Yellow crystalline precipitate.

CONFIRMATION **Na, K.**—Mix 1 part of the silicate with 5–6 parts of precipitated $CaCO_3$ and 1 part of NH_4Cl, heat to redness in platinum capsule for thirty minutes being careful to apply heat gently at first, digest sintered mass in hot water, and filter; to filtrate add $(NH_4)_2CO_3$ and NH_4OH, heat and filter, evaporate filtrate to dryness and ignite gently until all ammonium salts are driven off, then determine Na and K as above.

Residue a.—Boil with strong solution of $(NH_4)_2SO_4$ and filter.

Filtrate b.—Add a few drops of H_2S water; if any precipitate forms, saturate with H_2S and filter, and to filtrate add NH_4OH and $(NH_4)_2C_2O_4$.

Ca.—A white precipitate.

Residue b.—Moisten with concentrated HCl and try coloration of flame.

Ba.—Yellowish-green flame.

Sr.—Scarlet flame.

CONFIRMATION **Ba and Sr.**—Fuse residue b with two to three pts. of soda in a platinum capsule: treat fusion with boiling water, filter, reject filtrate, dissolve residue in acetic acid, add a few drops of H_2S water, if it gives any precipitate, saturate with H_2S and filter, and to filtrate add $K_2Cr_2O_7$. **Ba** = yellow precipate. Filter, and to filtrate add $CaSO_4$ warm and let stand. **Sr** = white precipitate.

PART III.

DESCRIPTIVE MINERALOGY.

CHAPTER XIV.

DESCRIPTIVE TERMS.

Definition of Minerals.

The solid crust of the earth is composed principally of "minerals" each mineral being a homogeneous substance of definite chemical composition, found ready-made in nature, and not directly a product of the life or the decay of an organism.

Chemical Salts.

The line is arbitrarily drawn The manufactured chemical substance is not a mineral although the chemist's laboratory and Nature employ the same forces and produce some substances identical in all respects.

Natural substances are usually not easily imitated because the important element of long periods of time cannot be given to the manufacture of the substance. On the other hand most manufactured compounds are too soluble and perishable to exist long as natural salts.

Natural Substances of Organic Origin.

Materials which have formed part of living organisms, coal, chalk, pearls, coral, shells, etc., are not minerals. If by natural agencies their organic structure is lost and a new crystalline structure obtained they become minerals. That is their components may recombine or combine with other elements to form minerals.

Rocks.

A rock is a mineral mass which for a considerable depth and area is of fairly constant character. It sometimes consists entirely of one mineral, much more frequently of two or more minerals, and may consist in part of organic remains.

The resolution of these rocks into their component minerals and the study of these minerals belong to Mineralogy. The study of these rocks, as such, is referred to Petrography and Geology.

The Study of Minerals or "Mineralogy."

Mineralogy considers the one thousand or so definite minerals and the many thousands of varieties and doubtful species which constitute the solid crust of the earth. Its purpose is the study of all the qualities of these minerals; their chemical composition as revealed by analyses; their molecular structure as revealed by crystalline form and by physical tests, and their origin and mode of formation as revealed by associated minerals, the alterations which they undergo and their synthetic production.

In elementary work in mineralogy, especially in a technical course, the principal object is the acquisition of an "eye knowledge" of the common and commercially important minerals so that they may be recognized at sight or determined rapidly by a few simple tests. This knowledge can be acquired only by handling and testing many labelled and unlabelled specimens, and is best preceded by a thorough drill in the use of the blowpipe and a study of models and natural crystals. With this there should be gained a knowledge of their characters, economic uses and occurrence.

A Mineral Species.

No one character will determine a species, but chemical composition and crystalline form together will do so, for it is found that whenever both of these characters are constant in different specimens, or vary only in accordance with known laws, then all other important characters * are constant and the specimens belong to the same species.

The Two Conditions in Which Minerals May Occur.

The Crystalline Condition. — A mineral is sometimes defined as a natural crystal, that is, being a chemical substance, it should possess a crystalline structure and occur either in crystals of characteristic shapes or in masses made up of many little crystals so crowded together that the shapes are not evident.

In the crystal and in each grain of the aggregation the crystalline structure will be shown by the constancy of the properties in parallel directions and their variation in directions not parallel.

* Structure, habit, color and form of aggregation are considered non-essential characters.

The Amorphous Condition. — A few glassy and earthy minerals have never been found in crystals and in the mass fail to show any regular crystalline structure. Opal is the best example. Such minerals are said to be *amorphous.* The number is very small, but certain varieties of minerals which crystallize may, from rapid cooling or other cause, be apparently amorphous.

Habit.

Although, as previously explained, the angles and forms which occur on different crystals of any substance are fixed and characteristic, the prevailing conditions at formation may cause more rapid growth in one direction than another. The term *habit* is used to express this relative development of the faces as distinguished from form or forms which may be exactly the same while the habit is very different.

The principal terms of habit are:

Prismatic. — Notably elongated in one direction whether that is the direction of the prism or not.

Tabular. — Two parallel faces are much larger than the others.

Pyramidal. — The dominant faces meet in a point or a pair of opposite points.

Acicular. — In long thin needle-like crystals.

Capillary. — In hair-like or thread-like crystals.

Irregularities of Faces of Crystals.

The perfectly smooth and plane crystal face is difficult to find, except in very minute crystals.

Striated Faces. — Crystal faces are frequently marked by parallel

FIG. 249.

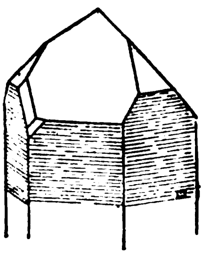
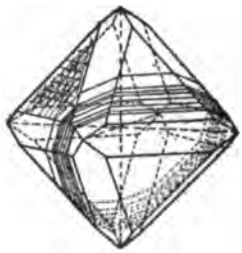


FIG. 250.



lines or fine "grooves" called "striations," each of which is bounded by two definite planes. They may result from:

1. An oscillation or contest between two crystal forms as in the

case of the striations on the prism faces of quartz, Fig. 249, which are due to an alternate formation of prism and rhombohedron; or the striations on pyrite due to an oscillation between the cube and the pyritohedron, Fig. 251.

2. A repeated twinning of small individuals which together make

FIG. 251.

Striated Pyrite, Aspen, Col. After S. Smillie.

the whole crystal. If the individuals are thin the reëntrant angles become grooves or striations. Fig. 250 shows twinning striations on a magnetite crystal from Port Henry, N. Y.*

Drusy Faces. — Closely covered with minute crystals, giving a

FIG. 252.

FIG. 253.

rough surface like sandpaper. Often showing by their simultaneous glistening that they are parallel.

Curved Faces. — Crystals may appear curved because composed of individual smaller crystals only approximately parallel, as in dolomite, or siderite. Sometimes there result from this cause very

* Fig. 195 shows coarser repeated twinning on albite.

peculiar shapes as in the worm-shaped crystal of corundum,* Fig. 252, which is composed of layers, each a hexagonal pyramid cut off by the basal pinacoid. At other times the curving may be due to pressure after formation, which may be accompanied by a breaking of the crystal as in the tourmaline, Fig. 253.

Curvature of faces is often due to a series of vicinal faces each nearly parallel to the preceding.

Vicinal Faces.—Often prominent faces with simple indices are replaced wholly or in part by flattened pyramids, the faces of which do not obey the law of rational indices. The angles of these vary in different crystals. They seem to result whenever there is a rapid deposition, but at the same time concentration currents which are too feeble to completely cover the larger faces.

They are of importance because, like etch figures, they usually belong to forms which prove the true symmetry of the crystal rather than to the simple forms common to several classes.

Corroded and Etched Faces.— The faces are often corroded by natural agencies, and many show natural etch figures similar to the artificial etch figures described on p. 148.

Hollow Crystals.— Rapid growth may result in deep depressions on each face, giving hopper shaped or skeleton crystals.

Inclusions.— Foreign substances may be shut in a crystal during rapid solidification, as in the case of drops of water or bubbles of

FIG. 254.

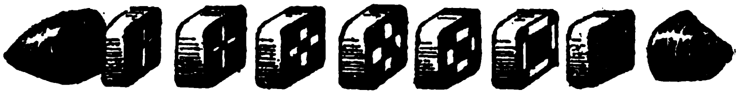
FIG. 255.

gas in quartz, or of sand in the crystals of calcite called Fontainebleau limestone, Fig. 254, which while retaining a form proper to calcite, contains sometimes as much as sixty per cent. of silica.

* H. Barvir, Beiträge zur Morphologie des Korund, *Ann. K. K. Hofmuseums*, VII., 1892, p. 141.

At other times the inclusions are material which the process of crystallization has tried to eliminate from the crystal. In such a case the included material is apt to be definitely arranged as in the case of the magnetite in mica from Chandler's Hollow, Del., Fig.

FIG. 256.



255, which is deposited on the cleavage planes of the mica and parallel to the mica prism of 120 degrees. This is also illustrated by the regular grouping of the purer white and less pure dark portions in chiastolite as shown in successive sections of a crystal in Fig. 256.

FIG. 257.

At times definite earlier formed minerals are included such as the little curved crystals of chlorite (helminth), Fig. 257, frequently found in quartz and feldspar, or the fine hair-like rutile in quartz, Fig. 258, while at other times the inclusions may be microscopic crystals (microlites) or incipient crystals (crystallites) not easily identified.

FIG. 258.

Rutile in Quartz, N. C.

REGULAR GROUPING OF CRYSTALS.

The grouping of crystals is sometimes a character of importance.

Twinning.

Twinning has already been described, pp. 61–66.

Parallel Growth.

A parallel arrangement of all corresponding faces and edges is frequently observed and may be recognized by the simultaneous reflection of light from all parallel faces. When the parallel crystals are minute they give a velvety appearance.

FIG. 259.

Copper with Analcite, Lake Superior; Columbia University.

Fig. 259 shows parallel cubes of copper with a crystal of analcite.

In certain instances the union of many crystals in parallel position results in larger crystals, either of the same form with slightly curved faces as in dolomite, or of a different form, as in the formation of octahedral fluorite by the union of cubes.

Crystals of a mineral may be capped by crystals of the same mineral the structures strictly parallel, but the forms not necessarily alike. Examples are:

Nail head Spar. — Calcite rhombohedra capping scalenohedra, but with cleavage directions parallel.

Sceptre Quartz. — Thin crystals capped by stouter ones.

Phantom Effects. — An earlier stage of growth delicately outlined as in quartz, gypsum and fluorite.

Capped Quartz. — During the growth of a crystal the planes at certain intervals may be coated with dust or fine lamellæ of a foreign substance and later the crystal may grow further. This may be repeated several times, forming thus parallel planes of easy separation, *e. g.*, capped quartz.

Parallel groupings sometimes occur which are less simple than the above, thus Dana describes* crystallized copper occurring in groups like Fig. 261, composed of cubes each twinned parallel to

FIG. 260.

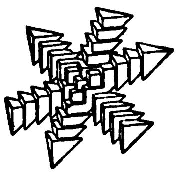


FIG. 261.

an octahedral face and these twins united in parallel position so as to form branches at sixty degrees to each other as shown in ideal form, Fig. 260.

Two crystals may be united so that a face or an edge of one are parallel to a corresponding part of another; for example staurolite and cyanite with brachy pinacoids parallel; prisms of rutile on hematite with the prism edge of rutile perpendicular to an edge of hematite and the prism face of rutile in contact with basal plane of hematite.

IRREGULAR GROUPING OF CRYSTALS.

Radiating. — Diverging from a common center, sometimes forming nearly complete spheres, as in pectolite from Paterson, Fig. 262. More frequently forming partial spheres, as shown in wavellite, Fig. 479.

* *Am. Journ. Sci.*, XXXII., p. 428, 1886.

Cockscomb. — A variety of radiating, but in which there is a partial parallelism and the free ends of the crystals form a ridge as in the specimen of Calamine, Fig. 264.

FIG. 262.

Pectolite, Paterson, N. J.

FIG. 263.

Stibnite, Felsobanya, Hungary.

Rosette Shaped. — The crystals overlapping like the petals of a rose as in hematite, Fig. 337.

FIG. 264.

Calamine, Franklin, N. J.

Reticulated. — Crossing like the meshes of a net, as in Fig. 263 of stibnite.

Geode. — A hollow nodule lined with crystals.

CRYSTALLINE AGGREGATES.

While the definite crystal is the simplest proof of crystalline structure, masses which do not show a single crystal face are usually aggregations of crystals which have been hindered by lack of room or other causes from assuming their characteristic forms. Such imperfectly developed crystals possess the regular internal structure.

This is often proved by the fact that either the entire mass may be split (cleaved) parallel to definite planes or different portions may each be so split parallel to its own set of planes. Mineral masses which are not opaque if examined by polarized light, as explained, Chapter XVIII., produce effects upon the light entirely different from those produced by a substance with indefinitely arranged particles, and the regular structure may be proved by other physical tests.

INTERNAL STRUCTURE OF AGGREGATES.

The internal structure of a crystalline aggregate depends upon the shape and grouping of the imperfect crystals. The important terms used are:

Columnar Structure.

The internal structure is said to be columnar when the imperfectly formed crystals are relatively long in one direction and

FIG. 265.

Beryl, Acworth, N. H. N. Y. State Museum.

FIG. 266.

Cyanite, Litchfield, Ct. N. Y. State Museum.

FIG. 267.

Fibrous Serpentine, Danville, Quebec. N. Y. State Museum.

grouped. Fig. 265 shows a columnar beryl. The columns may be parallel or not.

Bladed. — A variety of columnar in which the columns are flattened like a knife blade, as in cyanite, Fig. 266.

Fibrous. — A variety of columnar in which the columns are slender threads or filaments due to simultaneous growth from closely adjacent supports, as in Fig. 267, of the serpentine of Quebec, Canada.

Lamellar Structure.

The structure is said to be lamellar when the imperfectly shaped

FIG. 268.

Granular Magnetite, Mineville, N. Y. N. Y. State Museum.

crystals appear as layers or plates, either straight or curved, as in the mineral talc.

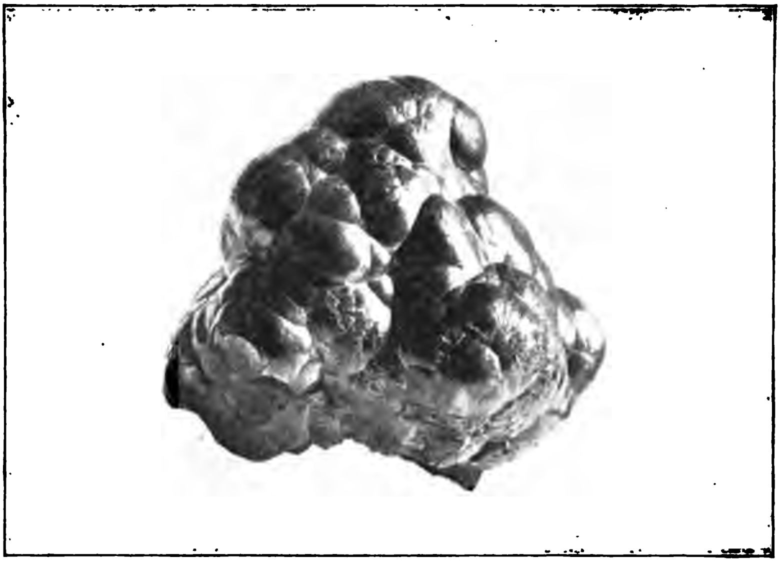
Foliated. — A variety of lamellar, in which the plates separate easily.

Micaceous. — A variety of lamellar in which the leaves can be obtained extremely thin, as in the micas.

Granular Structure.

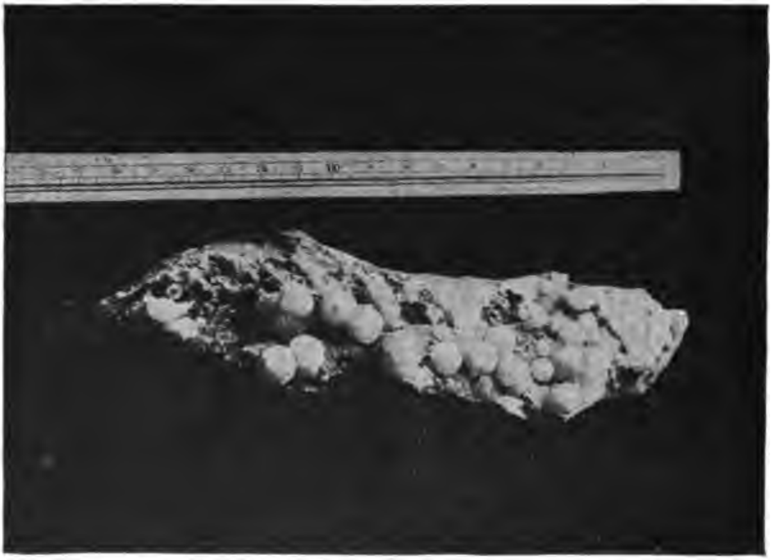
The structure is said to be granular when the imperfectly shaped

FIG. 269.



Kidney Ore (Hematite), Cleator Moor, England. N. Y. State Museum.

FIG. 270.



Botryoidal Prehnite, West Paterson, N. J. N. Y. State Museum.

crystals appear as angular grains, which may be coarse as in magnetite, Fig. 268, or fine, as in statuary marble.

Impalpable. — A variety of granular in which the grains are invisible to the unassisted eye.

THE EXTERNAL FORM OF AGGREGATIONS.

Many terms are used, based upon a fancied resemblance to some natural object. The more important of these are :

Reniform. — With the general shape of a kidney, as in hematite, Fig. 269.

Botryoidal. — Having something of the appearance of a bunch of grapes, being made up of several globular individuals close together, as in prehnite, Fig. 270.

Nodular. — Occurring in separate rounded lumps or nodules.

FIG. 272.

Mica, Minot, Me.

FIG. 271.

Limonite, Hungary.

FIG. 273.

Stilbite, Blomidon, N. S.

Pisolitic. — Composed of small rounded particles the size of a pea, as in bauxite, Fig. 477.

Oölitic. — Similar but smaller like fish roe as in hematite or calcite.

Stalactitic. — In hanging cones or cylinders like icicles, as in calcite or limonite, Fig. 271.

Plumose. — Like a feather, as in a variety of mica, Fig. 272.

Sheaf-like. — Resembling a sheaf of wheat, as in Fig. 273, of stilbite.

Arborescent or Dendritic. — Branching like a tree as in copper, Fig. 390, or pyrolusite, Fig. 274.

Mossy. — Similar to dendritic but a more minute structure, as the inclusions in moss agate.

Coralloidal. — Like coral in form as in "flos ferri."

FIG. 274

Pyrolusite, Florence, Italy.

Amygdaloidal. — Almond-shaped kernels filling cavities made by steam or gas, as in thomsonite.

Wire-like. — As in silver, Fig. 411.

CHAPTER XV.

CHARACTERS DEPENDENT ON COHESION AND GENERAL CHARACTERS.

THE various resistances opposed by a crystalline substance to forces tending to move or separate its particles give rise to a series of characters.

CLEAVAGE AND PARTING.

Many crystallized substances when sharply struck or when pressed with a knife edge split into fragments bounded by smooth plane surfaces which are always parallel to faces of simple forms* in which the substance can crystallize.

These surfaces are more splintery than the true crystal faces but the angles between them are just as exact as the interfacial angles.

When the separation can be obtained with equal ease in any part of the crystal and there is only a mechanical limit to the thinness of the resulting plates, the character is called *cleavage*. When, however, the separation can be obtained only at irregular intervals the character is called *parting*. Furthermore, all crystals of the same substance show the same cleavage, whereas parting may be obtained in one crystal and not in another.

When cleavage or parting is obtained parallel to one face of a crystal form it will be obtained with equal ease parallel to *all* faces of the form. For instance, galenite cleaves parallel to *all* planes of the cube, Fig. 275; calcite, Fig. 276, in three directions parallel to *all* the faces of a rhombohedron with diedral angles of 105° 5′; and some crystals of hematite show parting planes parallel to *all* the faces of the rhombohedron.

Cleavage may be obtained parallel to the faces of two or more crystal forms, for instance gypsum splits easily into plates parallel to the clino-pinacoid, these plates again break parallel to the ortho-

* Usually parallel to the simpler and more frequently occurring crystal forms; in the *isometric system* to the cube, octahedron or dodecahedron; in the *tetragonal* and *hexagonal systems* to the basal pinacoid, prism or rhombohedron and only rarely the pyramid. In the other systems the arbitrary selection of axes prevents a simple statement.

pinacoid and to the dome $\{\bar{1}01\}$ and the final shape is a rhombic plate with angles of 66°.

Terms of Cleavage. — Cleavage is said to be *perfect* or *eminent* when obtained easily, giving smooth, lustrous surfaces. Inferior

FIG. 275.

Galenite Cleavage, Pyrenees, after Lacroix.

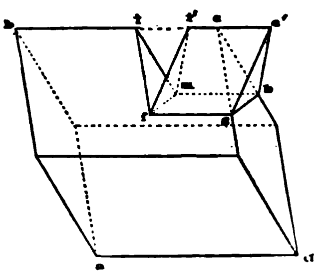
degrees of ease of cleavage are called *distinct, indistinct* or *imperfect, interrupted, in traces, difficult.*

Manipulation. — Directions of cleavage are often indicated by a pearly lustre on faces parallel to the cleavage direction, the lustre being due to repeated light reflections from cleavage rifts, or

FIG. 276.

Calcite Cleavage.

FIG. 277.



cracks may be visible. The absence of indications is not proof that cleavage cannot be obtained, but only that previous pressure or shock have not started the separation.

Cleavage is usually obtained by placing the edge of a knife or small chisel upon the mineral parallel to the supposed direction of cleavage and striking a quick, sharp blow upon it with a hammer. In some instances the cleavage is produced by heating and suddenly plunging the mineral in cold water. Sudden heat alone will often produce decrepitation and with easily cleavable minerals the fragments will be cleavage forms.

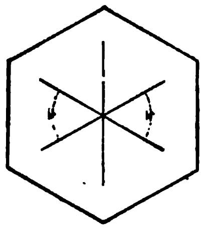
Frequently the cleavage is made apparent during the grinding of a thin section.

Parting is a secondary character produced in some instances and not in others as a result of pressure after solidification. It takes place along a so-called glide plane.*

PERCUSSION FIGURES.

If a rod with a slightly rounded point is pressed against a firmly supported plate of mica and tapped with a light hammer, three little cracks will form, radiating † from the point, Fig. 278. The most distinct of these is always parallel to the clino-pinacoid, the others at an angle *x* thereto which is 53° to 56° in muscovite, 59° in lepidolite, 60° in biotite, 61° to 63° for phlogopite.

FIG. 278.



In the same way on cube faces of halite a cross is developed with arms parallel to the diagonals of the face. On an octahedral face a three-rayed star is developed.

ELASTICITY.

Elasticity is capable of exact measurement, but is of little value in determination of minerals. The following terms are used:

Elastic.—A thin plate will bend and then spring back to its original position when the bending force is removed, as in mica.

Flexible or Pliable.—A thin plate will bend without breaking, as in foliated talc.

---

* The artificial development of a glide plane *fgbm* in calcite is shown in Fig. 277.

If the edge *ad* of the larger angle is rested upon a steady support and the blade of a knife pressed steadily at some point *i* of the opposite edge, the portion of the crystal between *i* and *c* will be slowly pushed into a new position of equilibrium as if by rotation about *fgbm* until the new face *gc′b* and the old face *gcb* make equal angles with *fgbm*.

† By pressure alone, three cracks diagonal to these are developed.

TENACITY.

The following terms are used:

Brittle.—Breaks to powder before a knife or hammer and cannot be shaved off in slices.

Sectile.—Small slices can be shaved off which, however, crumble when hammered.

Malleable.—Slices can be shaved off which will flatten under the hammer.

Tough.—The resistance to tearing apart under a strain or a blow is great.

Ductile.—Can be drawn into wire. Every ductile mineral is malleable and both are sectile.

The sectile minerals are: graphite, bismuth, copper, silver, gold, platinum, chalcocite, agentite, molybdenite, orpiment, tetradymite, senarmontite, arsenolite, cerargyrite.

FRACTURE.

When the surface obtained by breaking is not a plane or a step-like aggregation of planes it is called a *fracture* and described as:

FIG. 279.

Conchoidal, rounded and curved like a shell, Fig. 279.

Even, approximately plane.

Uneven, rough and irregular.

Hackly, with jagged sharp joints and depressions as with metals.

Splintery, with partially separated splinters or fibers.

HARDNESS.

The resistance of a *smooth* plane surface to abrasion is called its hardness, and is commonly recorded* in terms of a scale of ten common minerals selected by Mohs:

* In more exact testing the crystal may be moved on a little carriage under a fixed vertical cutting point and the pressure determined, which is necessary to produce a visible scratch. Other methods are planing or boring with a diamond splinter under constant pressure, and comparing the loss in weight for a given penetration or given number of movements. The loss of weight during grinding and the pressure necessary to produce a permanent indentation or a crack have also been used as determinants of hardness.

1. *Talc*, laminated.
2. *Gypsum*, crystallized.
3. *Calcite*, transparent.
4. *Fluorite*, crystalline.
5. *Apatite*, transparent.
6. *Orthoclase*, white cleavable.
7. *Quartz*, transparent.
8. *Topaz*, transparent.
9. *Sapphire*, cleavable.
10. *Diamond*.

A good method is to try the hardness of the mineral first with the finger nail, or a copper coin, then with a pocket knife, then with the indicated members of the scale.

1, 2 (2½ barely), scratched by finger nail.
3, scratches and is scratched by a copper coin.
3, 4, 5 (5½ barely), scratched by a knife.
6, 7, 8, 9, 10, not scratched by a knife.

The hardness having been approximately judged by the ease with which the knife, finger nail or copper coin, cuts the mineral, is checked by the nearest member of the scale. If the knife does not scratch the specimen the harder members, 6 to 10, are used successively until one is found which scratches the mineral.

In testing, some inconspicuous but smooth surface of the substance is selected and a sharp corner of the standard mineral is pressed upon the surface and moved back and forth several times on the same line a short distance (⅛ inch). If the mineral is not scratched it is harder than the standard used, and the next higher on the scale is tried in the same way.

Care must be taken to distinguish between a true scratch and the production of a "chalk" mark which rubs off. Altered surfaces must be avoided.

ETCHING FIGURES.

When a crystal or cleavage is attacked by any solvent the action proceeds with different velocities in crystallographically different directions, and if stopped before the solution has proceeded far, the crystal faces are often pitted with little cavities of definite shape.

The absolute shape varies with many conditions; time, temperature, solvent, crystallographic orientation and chemical composition.

The figures, *whatever their shape*, conform in symmetry to the class to which the crystal belongs, and are rarely forms common to several classes. They are alike on faces of the same crystal form and generally unlike on faces of different forms, and serve, therefore, as an important means (perhaps the most important) for

determining the true grade of symmetry of a crystal and also for recognizing and distinguishing faces.

Fig. 280 shows the shape and direction of the etchings upon a cube of pyrite. These conform to the symmetry of the group of the diploid, p. 59. On the other hand the etchings upon a cube

FIG. 280.

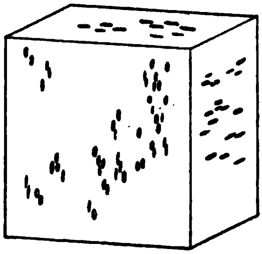
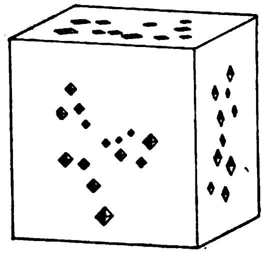


FIG. 281.



of fluorite, Fig. 281, show a higher symmetry corresponding to that of the hexoctahedral group, p. 52.

The etchings of wulfenite, Fig. 283, show the mineral to belong to a class of lower symmetry than that suggested by the form,

FIG. 282.

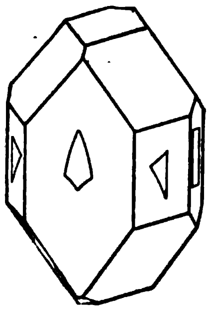
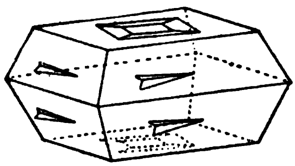


FIG. 283.



while the etchings of pyroxene, Fig. 282, like the form, are symmetrical to one plane.

THE GENERAL CHARACTERS.

By the general characters of minerals may be understood those characters which do not appear to be dependent upon the crystalline structure. The principal are: specific gravity, specific heat, taste, odor and feel.

SPECIFIC GRAVITY.

The specific gravity of a substance is equal to its weight divided by the weight of an equal volume of distilled water. The character

is an unusually constant one, the variations in varieties of the same species not being great and even these being due usually to actual differences in composition.

Strictly the temperature of the water should be 4° C., or if not the result should be multiplied by a factor which is the specific gravity of the water used. Generally the water is used at the ordinary room temperature without correction.

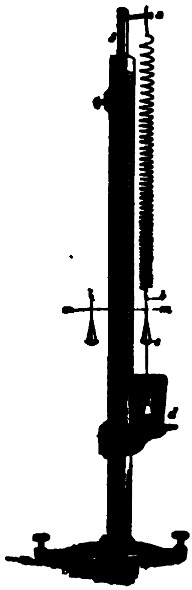
Pure material must be selected free from cavities, and air bubbles clinging to the surface must be brushed off while the fragment is in the water.

Substances soluble in water must be determined in alcohol, benzine or other liquids in which they are insoluble, and the result multiplied by the specific gravity of the liquid used.

The specific gravities of the minerals considered in this book range from water (ice) 0.92, to iridosmine 19 to 21.

Minerals of metallic and submetallic luster are heavy, rarely as low as 4. The great group of silicates range chiefly between 2 and 3.5, zircon reaching 4.7. With the exception of the lead salts practically all the other minerals here considered lie between 2 and 4.

FIG. 284.



Using the Chemical Balance.

In using an ordinary chemical balance the fragment is first weighed (W) and then suspended from one scale pan, by a hair or very fine platinum wire, in a glass of water and reweighed (w). If platinum wire is used it must be counterbalanced.

$$\text{Sp. Gr.} = \frac{W}{W - w}.$$

Using the Jolly Balance.

In using the Jolly balance, Fig. 284, the lower scale pan is *kept submerged;* three readings are made by noting the heights at which the index on the wire and its image in the graduated mirror coincide with the line of sight when the spiral comes to rest.

A. Instrument reading with nothing in either scale pan.

B. Reading with mineral in upper scale pan.

C. Reading with same fragment transferred to lower scale pan.

$$\text{Sp. Gr.} = \frac{B - A}{B - C}.$$

Using the Pycnometer or Specific Gravity Flask.

Very porous minerals and powders are determined by weighing in a little glass bottle the stopper of which ends in a fine tube. In a later form there are two openings, one, the neck, is closed by a ground stopper carrying a thermometer, the other ends in a capillary tube.

In ordinary use the mineral is weighed (A) and the bottle full of water is also weighed (B). The mineral is then inserted in the bottle and displaces its bulk of water, and the difference between this weight (C) and the sum of the other two weights is the weight of the displaced water.

$$\text{Sp. Gr.} = \frac{A}{B + A - C}.$$

If special precautions * are used this apparatus may be relied upon to the third decimal with one gram of substance.

Complete removal of air bubbles is secured by placing the pycnometer under an air pump after the fragments are covered with the liquid.

Using Heavy Liquids.

If a fragment of a mineral, which may be very minute, is dropped into a test-tube containing a liquid of higher specific gravity it will float. If the liquid is diluted, the diluent being stirred in drop by drop, there will be one stage at which the fragment if pushed down will neither sink nor rise but stay where pushed.

The specific gravity of the liquid is then determined either roughly by dropping in fragments of material of known specific gravity until one is found which just sinks and another which floats, the liquid being of a specific gravity between these; or for more accurate determination the most convenient balance is that of Westphal, Fig. 285. The beam is graduated in tenths and the weights A, B and C are respectively unit, $\frac{1}{10}$ and $\frac{1}{100}$.

This balance is so constructed that when the thermometer float is suspended in distilled water at 15° C. a unit weight must be hung at the hook to obtain equilibrium.

If then the test-tube is nearly filled with the heavy liquid and weights added until equilibrium is secured the specific gravity is known.

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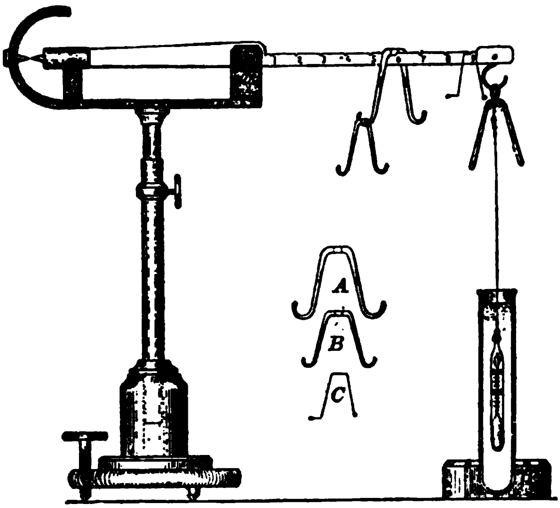
* See Mier's *Mineralogy*, p. 191.

For instance in the figure the weights employed are:

Unit weight at hook, value	1.000
Unit weight at sixth division, value	0.600
$\frac{1}{10}$ weight at sixth division, value	0.060
$\frac{1}{100}$ weight at ninth division, value	0.009
Specific gravity	1.669

FIG. 285.



The Westphal Balance.

The principal heavy liquids are: *

Thoulet Solution. — Mercuric iodide and potassium iodide, in the ratio of five parts to four by weight, are heated with a little water until a crystalline scum forms, then filtered. The maximum specific gravity is nearly 3.2 and may be lowered by the addition of water to any desired point.

Klein Solution. — Cadmium borotungstate with a maximum specific gravity of 3.6.

Braun's Solution. — Methylene iodide, CH_2I_2, with a maximum specific gravity of 3.32 which can be lowered by the addition of benzol. It darkens from exposure to light but may be clarified by shaking with a little mercury.

By addition of iodoform and iodine it may be raised to a specific gravity of 3.65.

* See *Neues Jahrb. f. Min.*, 1889, II., 185, for list of solids which when melted have specific gravity up to 5.

Penfield Solution. — Silver thallium nitrate which is liquid at 75° C., has a maximum specific gravity of over 4.5 which can be lowered by the addition of hot water.

SPECIFIC HEAT.

This general property has not been used for the identification of minerals. It may be defined as the amount of heat needed to raise the temperature of a substance one degree, divided by the amount of heat necessary to raise the same weight of water one degree.

The usual method consists in heating the coarsely crushed mineral, then cooling in water, then:

$W =$ weight of mineral.
$w =$ weight of water.
$T =$ degrees final temperature mineral exceeded initial.
$t =$ degrees final temperature water exceeded initial.

$$\text{Specific Heat} = \frac{wt}{WT}.$$

TASTE.

Minerals soluble in water often have a decided taste:

Astringent. — The taste of alum.
Saline or Salty. — The taste of common salt.
Bitter. — The taste of epsom salts.
Alkaline. — The taste of soda.
Acid. — The taste of sulphuric acid.
Cooling. — The taste of nitre.
Pungent. — The taste of sal-ammoniac.

ODOR.

Odors are rarely obtained from minerals, except by setting free some volatile constituent. The terms most used are:

Garlic. — The odor of garlic obtained by heating minerals containing arsenic.

Horseradish. — The odor of decayed horseradish obtained from minerals containing selenium.

Sulphurous. — The odor obtained by heating sulphur or sulphides.

Fetid. — The odor obtained by dissolving sulphides in acid.

Bituminous. — The odor of bitumen.

Argillaceous. — Obtained from serpentine and some allied minerals, after moistening with the breath.

FEEL.

Terms indicating the sense of touch are sometimes used:

Smooth. — Like celadonite or sepiolite.

Soapy. — Like talc.

Harsh or Meager. — Like aluminite.

Cold. — Distinguishes gems from glass.

CHAPTER XVI.

THE OPTICAL CHARACTERS WHICH ARE OBSERVED BY COMMON LIGHT.

LUSTRE.

THE lustre of a mineral is dependent upon its refractive power, its transparency and its structure. It may be called the *kind* of brilliancy or shine of the mineral.

METALLIC lustre is the lustre of metals. It is exhibited only by opaque minerals, and these, with the exception of the native metals, have a black or nearly black streak.

NON-METALLIC lustre is exhibited by all transparent or translucent minerals. It may be vitreous, adamantine, resinous, pearly, silky, greasy or waxy.

Vitreous. — The lustre of a fracture surface of glass or of a quartz crystal. Index of refraction $n = 1.3$ to 1.8.

Adamantine. — The almost metallic lustre of the uncut diamond, zircon or cerussite, exhibited by minerals of high index of refraction. $n = 1.9$ to 2.5.

Resinous. — The lustre of resin or sphalerite.

Greasy. — The lustre of oiled glass or elæolite. $n = 1.7$ to 1.9.

Pearly. — The lustre of the mother of pearl or of foliated talc. Common parallel to a very perfect cleavage.

Silky. — The lustre of silk or of satin spar, due to a fibrous structure.

Dull. — Without lustre or shine of any kind. Kaolin or chalk are good examples.

The prefix sub, as sub-metallic, sub-vitreous, is used to express an imperfect lustre of the kind.

The words splendent, shining, glistening, glimmering and dull are terms of *intensity* dependent on the quantity of light reflected.

Lustre should, when possible, be determined by a comparison with minerals of known lustre, and should always be observed on a fresh or unaltered surface.

The degree and kind of lustre are always the same on like faces

of the crystal, but may be different on unlike faces, as in apophyllite, which has pearly basal pinacoid and vitreous prism faces.

COLOR.

The surface colors are of two classes.

1. Colors dependent on the chemical constituents.
2. Colors dependent on physical causes.

Color Dependent on Chemical Composition.

Color is one of the least constant mineral characters, and varies with different specimens of the same species. It is frequently changed by a few hundredths of one per cent. of some organic or inorganic substance dissolved in the mineral, or by larger amounts of mechanically included foreign material.

In describing color the terms white, gray, brown, black, blue, green, yellow and red are used, with prefixes, which suggest the shade by the color of some familiar object. These need no explanation.

Color Due to Physical Causes.

If the observed surface color changes with the direction in which it is viewed it is due to interference of light.

Play or Change of Colors. — A succession of colors, varying with the direction the mineral is viewed, as in opal, labradorite, or diamond.

Iridescence. — Bands of prismatic colors, either from the interior of a mineral, as from a thin film of air between cleavages; or external and due to a thin coating or alteration.

Tarnish. — A surface which has been exposed to the air or to moisture is often of different color from the fresh fracture.

Opalescence. — A milky or pearly reflection, sometimes an effect of crystalline structure, at other times due to fibrous inclusions.

Asterism. — A star effect by reflected light, as in the ruby, or by transmitted light, as in some micas, and due to structure planes or symmetrically arranged inclusions.

PHOSPHORESCENCE.

Many minerals, after being subjected to various outside influences, emit light which often persists for some time after removal of the exciting cause. Such emission of light is known as phosphorescence.

Phosphorescence may be induced by ordinary light, heat, friction, mechanical force or electrical stress but especially by the action of radium, polonium and actinium emanations, by X-rays and by ultra-violet light. In a particular specimen it may be induced by only one or by several of the agencies named. Phosphorescence is not always a characteristic of species but rather of the particular specimen or of species from a certain locality. On the other hand certain species are nearly always phosphorescent. Diamonds are generally strongly phosphorescent under radium emanations, but the degree of reaction varies with the individual specimen. They also phosphoresce under the influence of polonium, actinium, X-rays, ultra-violet rays and some rare specimens will glow in the dark even after exposure to sunlight or the light of the electric arc. Willemite from Franklin, New Jersey, and kunzite are strongly phosphorescent under the influence of radium, polonium, actinium and X-rays. Chlorophane, a variety of fluorite, phosphoresces at times by the simple heat of the hand, while fluorite itself may phosphoresce, fluoresce or do neither according to the specimen. All minerals from Borax Lake, California, phosphoresce under the influence of ultra-violet rays, which would seem to indicate some common phosphorescent constituent.

FLUORESCENCE.

Fluorescence is induced by much the same agencies as phosphorescence, but the emitted light, which may be white or colored, persists only during the action of the exciting agent. Colorless fluorite fluoresces under the influence of sunlight, autunite from Mitchell county, N. C., and hyalite from San Luis Potosi, Mexico, fluoresce wonderfully under the influence of ultra-violet light.

STREAK.

The streak of a mineral is the color of its fine powder. It is usually obtained by rubbing the mineral on a piece of hard, white material, such as unglazed porcelain, and brushing off the excess, or it may be obtained less perfectly by scratching the mineral with a knife or file, or by finely pulverizing a fragment of the specimen.

The streak often varies widely from the color of the mass and is nearly constant for any species. When not white it is a characteristic very useful in determination.

TRANSLUCENCY.

The translucency of a mineral is its capacity to transmit light. A mineral is said to be:

Transparent.—When objects can be seen through it with clearness.

Subtransparent.—When objects can be more or less indistinctly seen through it.

Translucent.—When light passes through, as through thin porcelain, but not enough to distinguish objects.

Subtranslucent.—When only the thin edges show that any light passes.

Opaque.—When no light appears to pass even through the thin edges.

REFRACTION.

When a ray of light passes from one substance into another in which its velocity is different, the ray is bent or refracted, and the amount of bending is found to be such that whatever the direction of the incident and refracted rays the ratio between the sines of the angles of incidence and refraction is constant.

Light incident at 90° is not bent, and with plane parallel plates the emerging light is parallel to the incident light.

Index of Refraction.

When light passes from air into a substance, this ratio between the sines is called the index of refraction of the substance, that is:

$$n = \frac{\sin i}{\sin \rho}.$$

Each singly refracting (isometric) mineral will have its characteristic index of refraction *for light of each wave-length*, while for doubly refracting minerals there will be *two indices* of refraction for each direction of transmission.

Approximate Determination of the Index of Refraction.

The index of refraction may be approximately determined by immersing small fragments of the mineral in a series of liquids of known refractive indices.* If the mineral and the liquid have nearly the same indices the light will go through without

* The indices of a few convenient liquids are: water, 1.34; alcohol, 1.36; glycerine, 1.41; olive oil, 1.47; nut oil, 1.50; clove oil, 1.54; aniseed oil, 1.58; almond oil, 1.60; cassia oil, 1.63; monobromnapthalene, 1.65; methylene iodide, 1.75.

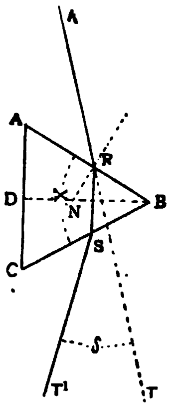
noticeable bending and the outline and roughnesses will be invisible, but if they differ materially the roughness will be distinctly visible.

F. Krantz, of Bonn, furnishes * a series of 21 liquids in glass-stoppered bottles, the indices of the liquids ranging from 1.447 to 1.83.

Measurement of Indices of Refraction.

The Prism Method.† — If monochromatic light is sent through the collimator c, Fig. 14, along a line KR, Fig. 286, and enters at one face AB of a prism of known angle X it will emerge at the other side BC, deviated from its course an angle δ. For one position of the prism, found by trial, this deviation δ is a minimum and bears a definite relation to the index of refraction n and the angle of the prism X expressed by

FIG. 286.

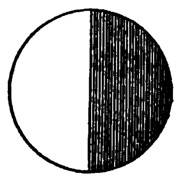


$$n = \frac{\sin \frac{1}{2}(\delta + X)}{\sin \frac{1}{2} X}.$$

In hexagonal and tetragonal crystals the indices determined are those obtained by transmission at right angles to the optic axis. Two images are found which may be distinguished by a nicol's prism, which transmits vibrations parallel to its shorter diagonal. In orthorhombic, monoclinic and triclinic crystals three indices are determined corresponding to rays vibrating parallel to the acute and obtuse bisectrices and a direction at 90° to both. At least two differently oriented prisms are necessary to secure these three indices.

The Total Reflection Method.‡ — A fragment with a natural or polished plane face is suspended so as to revolve about a vertical axis in a vessel filled with a liquid of higher refractive index than the crystal. Diffused light is admitted from the side and the crystal is viewed by a telescope fixed at 90° to the plane front of the vessel. For *one* position the field of the telescope appears as in Fig. 287. The light is then admitted at the opposite side and the plate turned until the field is again half light, half dark. The angle between these two positions is $2i$, and the index of the mineral is $n = n_1 \sin i$, in which n_1 is the known index of the liquid.

FIG. 287.



In hexagonal and tetragonal crystals both desired indices result from any crystal face.

* Price 12 marks.

† A. J. Moses, *Characters of Crystals*, p. 88.

‡ *Ibid.*, p. 90.

In orthorhombic, monoclinic and triclinic crystals all three indices can be obtained from any plane surface parallel to either bisectrix or the line at 90° to both.

DOUBLE REFRACTION.

If an object is viewed through a transparent cleavage of calcite,* it will appear to be double, as in Fig. 288. If such a cleavage is revolved about a horizontal axis at 90° to a face, any light ray, *IT*, incident at 90°, Fig. 290, is transmitted in the rhomb as two rays of essentially equal brightness (giving two images of any signal), and as the rhomb is turned about the axis one of these remains fixed in position, the other moves around the first.

FIG. 288.

With single refraction and normal incidence only the fixed image would have been seen, hence this is called the *ordinary* and the movable image by contrast the *extraordinary*.

That some peculiar change has taken place other than the division of the one ray into two may be shown as follows:

FIG. 289.

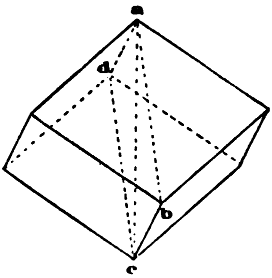
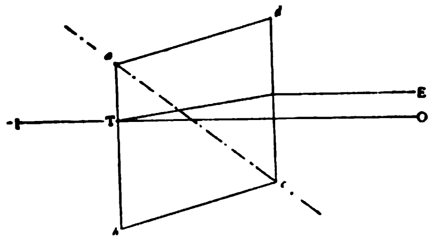


FIG. 290.



Let one of the two rays be shut off and the other viewed through a second calcite rhomb similarly mounted; this ray is again split into two rays, an ordinary and an extraordinary, but these *are no longer of equal brightness*, but wax and wane in turn, the sum of their intensities remaining constant.

Planes of Vibration.

The changes in intensity as the second rhomb is turned, corre-

* The property is common to all crystals except isometric, but calcite possesses it in a very marked degree. The double image can only be observed in a few substances, and the double refraction is better proved by the tests described later.

spond exactly to the assumption that the vibrations of common light have been converted by the first calcite into two sets of straight-lined vibrations, at right angles to each other, the one parallel to a plane through *ac* and *IT*, Fig. 290, the other at right angles to this plane.

The vibrations of either the extraordinary or the ordinary ray might be parallel to the plane through *ac*, but it is hereafter assumed *that the vibrations of the extraordinary ray are in a plane through the axis c, and those of the ordinary are at right angles to this plane.*

On this assumption the so-called "*Plane of Polarization*" of Malus is at right angles to the plane of vibration; that is, the plane of polarization of the *ordinary ray* is a plane through the axis *c*, and the plane of polarization of the *extraordinary ray* is at right angles to this. See Moses's *Characters of Crystals*, pp. 98–100.

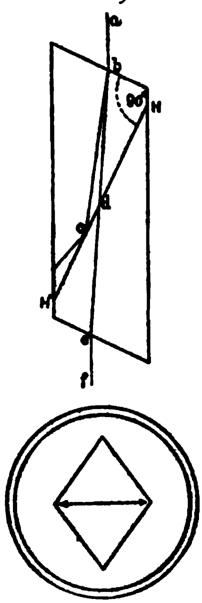
CHAPTER XVIII.

THE OPTICAL CHARACTERS OBTAINED WITH POLARIZED LIGHT.

Nicol's Prism.

Plane polarized light is produced from common light in several ways,* the principal one being transmission through a so-called nicol's prism, made from a cleavage of calcite with a length about twice its thickness, Fig. 291.

FIG. 291.



The two small rhombic faces at 71° to the edge are ground away and replaced by faces at 68° to the edge. The prism is then cut through by a plane at right angles both to the new terminal faces and to the principal section. The parts are carefully polished and cemented by Canada balsam, the index of refraction of which is 1.54 or about that of the extraordinary ray *bd*, which, therefore, passes through the balsam with but little change in direction; the ordinary ray *bc*, however, with an index of refraction of 1.658, being incident at an angle greater than its critical angle, is totally reflected.

The emerging light is no longer common light vibrating in constantly changing ellipses, but is plane polarized, vibrating parallel to a plane through the shorter diagonal of the face of the nicol, as shown by the arrow.

Crossed Nicols.

The term nicol is used to designate any form of polarizer. If two nicols are placed so that the light from one reaches the other, the light will go through unchanged if the faces of the

* Other similar prisms exist and other methods are:

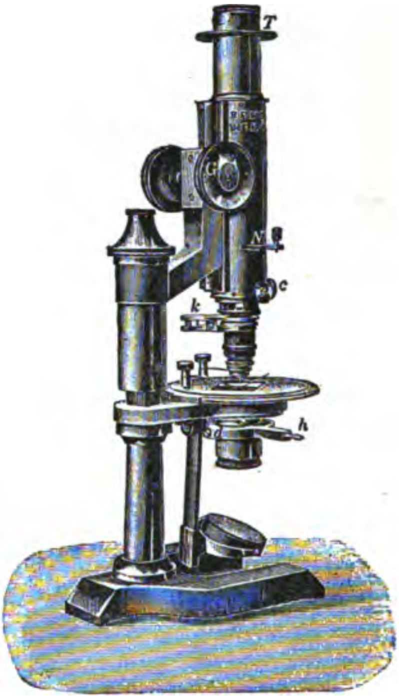
Reflection at a particular angle of incidence ($\tan i = n$), the vibrations being at right angles to the plane of reflection (plane through incident and reflected ray).

Refraction through a series of parallel glass plates, each plate increasing the proportion of polarized light. In this case the vibrations are in the plane of reflection.

Double refraction and absorption. Certain substances absorb one ray much more rapidly than the other, and a thickness can be chosen for which one ray is totally absorbed, the other being partially transmitted with vibrations all in one plane. Tourmaline is often used, as in this mineral the ordinary ray is much the more rapidly absorbed.

nicol are parallel, but as one is rotated the percentage of light emerging diminishes and after 90° of rotation, that is *with crossed nicols*, none of the light from the first nicol can penetrate the second and the field must be dark.

FIG. 292.



This may be illustrated by two nicol prisms set rather loosely in a hole bored in a block of wood.

Polarizing Microscope.

A polarizing microscope is essentially a pair of crossed nicols added to an ordinary microscope. Fig. 292 shows a simple type of Fuess. The mirror sends parallel rays through the lower nicol, which may be raised or lowered by the lever *h*. The upper nicol *N* has its vibration plane at right angles to that of the lower nicol and may be thrown in or out by a horizontal motion.

The revolving stage, the objective, eye piece and methods of focussing are like those of the ordinary microscope.

TESTS WITH PARALLEL RAYS OF POLARIZED LIGHT.

Depolarization.

If a section of any crystal, such as mica, is placed between crossed nicols, whether between two nicols in a wooden stand or upon the stage of a polarizing microscope, the dark field in general becomes light; whereas a plate of glass so inserted leaves the field dark.

The reason is that all crystals, except the isometric, are doubly refracting. The plate used has opposite parallel sides. The entering light is doubly refracted as in calcite and emerges as two parallel rays vibrating at right angles to each other, in directions not generally parallel to the vibration directions of the nicols.

Determining Extinction Directions between Crossed Nicols.

The *directions* of these vibrations vary with the section and substance, *but are constant* in parallel sections of *different* crystals of the same substance. Hence their position is a character of value.

Each section has two vibration directions at 90° to each other, which are known as *extinction directions* because whenever either is parallel to the vibration direction of the lower nicol the light goes through the plate unchanged in vibration direction, therefore still at 90° to the vibration of the upper nicol. The light is therefore unable to penetrate the upper nicol and the field is dark.

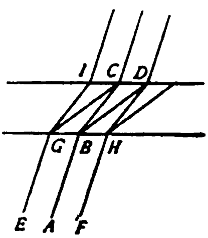
For every 90° this is true but for all other positions the field is illuminated by the components of the rays which penetrate the upper nicol. This brightening is most intense for positions diagonal to the extinction directions.

Manipulation. — Place the section, for instance a cleavage of mica, or of gypsum, on the stage of the microscope, focus with the upper nicol out, make some edge, cleavage or other outline coincide with a cross hair, read the vernier, push in the upper nicol and rotate the stage of the microscope until the *extinction direction* is found by the darkening * of the field. Again read the vernier. The difference between the two readings is the extinction angle with the chosen outline.

Destructive Interference, Monochromatic Light and Crossed Nicols.

If a ray of monochromatic polarized light AB, Fig. 293, strikes a crystal section, it is split into two rays moving, for example, in the directions BC and BD and on emergence at C and D each ray travels parallel to the original direction, therefore to each other. *These can not interfere.*

FIG. 293.



But some other ray EG parallel AB will have one resultant ray travelling along GC and emerging at C. The rays EGC, ABC *will interfere.* That is from each point of the upper surface there will emerge the ordinary component of one ray and the extraordinary

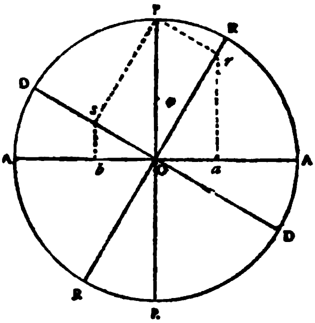
* Maximum darkness is not as easily judged as color, hence a closer determination may be made if the field is made red or violet by a gypsum or a quartz test-plate, and the mineral inserted so as to only partly cover the field. For the extinction positions, the mineral will appear of the same color as the rest of the field.

of another, and these rays will travel over the same path, but their vibrations will be at right angles to each other.

Furthermore one having travelled further in the plate and through a different structure will have been retarded a different amount than the other.

Effect of the Second Nicol. — Each of the two rays EGC, ABC will have a component in the direction of vibration of the second nicol *and these alone will be transmitted.* That is the two rays with vibrations at 90° will become two rays with parallel vibrations. If these vibrations are alike in phase the intensity of the resultant ray will be proportionate to the square of the sum of their amplitudes, but if unlike in phase the intensity will be proportionate to the square of their difference.

FIG. 294.



There is a shutting out of all light by destructive interference whenever one of the two rays just described is one, two, three, etc., wave-lengths ahead of the other.*

For let PP, Fig. 294, represent the entering vibration in direction and intensity, let RR and DD represent the extinction directions of the plate, and let P represent the position of vibration at the instant of entering the plate.

Then r and s will represent the corresponding positions of the component vibrations at the same instant.

FIG. 295.

When one of the two has gained, relatively, *just a wave-length* (or 2 or 3, etc.) the relative positions of the component vibrations are again r and s.

The components of Or and Os in the vibration direction AA of the second nicol are Oa and Ob, equal and opposite. That is the light vibration is stopped and darkness results for all positions of the revolving stage of the microscope.

Practical Confirmation. — A wedge † of doubly refracting sub-

* On the contrary the field is brightest when the faster ray is ahead $\frac{1}{2}\lambda$, $\frac{3}{2}\lambda$, $\frac{5}{2}\lambda$, etc., for now the components on AA are *equal and in the same direction.*

† Very distinct lines can be obtained from a little wedge of gypsum made by shaving down a cleavage with a sharp knife or better by rubbing it down.

stance will show, in monochromatic light, dark bands at regular intervals, which vary with the color of the light used and correspond to differences between the emerging rays of one, two, three, etc., wave-lengths.

Interference Colors with White Light and Crossed Nicols.

The difference between the two rays or "Retardation," Δ, as it is called, depends upon three factors: (*a*) the material, (*b*) the direction of transmission or orientation, (*c*) the thickness of the section. These being known Δ is known.

But this retardation Δ may be at the same time approximately an even multiple of the half wave-length of light of one color and an odd multiple of the half wave-length of light of another color. That is, the light of the first color would be very much weakened while that of the second color would be at nearly its full intensity and instead of white light there would result a tint due to a combination of these and other unequally dimmed colors.

Practical Example.

The effect can be determined from $\Delta = t\,(n_1 - n)$ in which Δ = relative gain of faster ray, t = thickness of section, λ = wave-length = 390 violet, 485 blue, 525 green, 590 yellow, 700 = red (all in millionths of a millimeter), $n_1 - n$ = difference in refractive indices usually called "the double refraction."

For fixing these relations in mind the following method may be used. A cleavage of mica or gypsum is tapered (wedged) at the edge after fastening to an object glass with Canada balsam (balsam in xylol is convenient).

1° The brightest interference color of the cleavage is noted by finding the extinction directions between crossed nicols and turning the stage 45°.

2° By the tapering edge or by use of a quartz wedge * the order of the color is determined from which a color chart will give the value of Δ.

3° The thickness t may be measured in a micrometer scale.

4° *The approximate strength of the double refraction* will result by dividing the value of Δ by the thickness of the section in millionths of a millimeter.

---

* By gradually inserting a thin wedge of quartz between the nicols so that the corresponding vibration directions are crossed and counting the number of times the original color reappears, if n times, then the color is a red, blue, green, etc., of $n + 1$ order, for which the value may be looked up in a color chart.

5° This may be checked by looking up a recorded value or by testing a second section of the same mineral of different thickness.

6° Finally the reason that the observed color corresponds to the value of $\triangle$ in the chart may be ascertained by dividing $\triangle$ by λ for each color, if the quotient is 1, 2, 3, 4, etc., or nearly, that color is shut out, if it is $\frac{1}{2}$, $\frac{3}{2}$, $\frac{5}{2}$, or nearly, then that shade or color is in nearly its full intensity. If it is intermediate then *a portion* of the color is extinguished.

For instance let $\triangle = 900\ \mu\mu$ (millionths of a millimeter).

Violet	$\frac{900}{390} = 2.3$,	nearer $2\frac{1}{2}$ than 2,	over $\frac{1}{2}$ present.
Blue	$\frac{900}{485} = 1.85$,	nearer 2 than $1\frac{1}{2}$,	over $\frac{1}{2}$ lost.
Green	$\frac{900}{525} = 1.72$,	nearer $1\frac{1}{2}$ than 2,	about $\frac{1}{2}$ present.
Yellow	$\frac{900}{590} = 1.52$,	closely $1\frac{1}{2}$,	all present.
Red	$\frac{900}{700} = 1.3$,	nearer $1\frac{1}{2}$ than 1,	over $\frac{1}{2}$ present.

The conclusion, therefore, is that the resultant color is composed of the yellow and over $\frac{1}{2}$ of the red and violet and $\frac{1}{2}$ or less than $\frac{1}{2}$ of the blue and green.

Another factor has weight however. The relative intensity of the colors in the spectrum are very unequal, possibly in order named about 1, $1\frac{1}{2}$, 2, 6, 2. Bringing this in we have violet $> \frac{1}{2} \times 1 = > \frac{1}{2}$, blue $< \frac{1}{2} \times 1\frac{1}{2} = \frac{1}{2}$ approx., green $\frac{1}{2} \times 2 = 1$, yellow $1 \times 6 = 6$, red $> \frac{1}{2} \times 2 = > 1$. That is, yellow greatly predominates. The red and green balance and the blue and violet slightly tint the yellow.

The Vibration Directions of the Faster and Slower Rays.

The extinction directions in the section are found and placed in diagonal position, a test plate of some mineral, in which the vibration directions have been distinguished and marked, is inserted between the nicols (in a slot provided) with these directions also diagonal. If the interference color is thereby made higher, as shown by the color chart, the vibration direction of the faster ray of the section is parallel to the faster ray in the marked plate; if the color is lowered, the corresponding directions of vibration are crossed.

The test plates most used are:

QUARTER UNDULATION MICA PLATE.—A thin sheet of mica on which is marked c, the vibration direction of the slower ray, which in mica is the line joining the optic axes. The thickness chosen corresponds to $\Delta = 140\,\mu\mu$ which is $\frac{1}{4}\,\lambda$ for a medium yellow light and yields a blue gray interference color.

GYPSUM RED OF FIRST ORDER. — A thin cleavage of gypsum on which is usually marked $\mathfrak{a}$, the vibration direction of the faster ray. The thickness chosen corresponds to an interference color of red of first order, or say $\Delta = 560 \mu\mu$, which is essentially λ for a medium yellow.

DISTINGUISHING THE "SYSTEM" IN SECTIONS BETWEEN CROSSED NICOLS WITH PARALLEL POLARIZED LIGHT.

The polarizing microscope with the cross hairs parallel to the vibration planes of the polarizer and analyzer and parallel faced plates, either natural faces or cleavages or cut sections, are used.

Isometric Crystals.

Homogeneous isometric crystals will show no interference phenomena when viewed between crossed nicols, that is the field will be dark throughout thc complete rotation of the stage.

Tetragonal and Hexagonal Crystals.

In all tetragonal and hexagonal crystals light is transmitted in the direction of the vertical axis without double refraction. In all other directions it is doubly refracted, and the amount of refraction in any crystal is constant for all directions equally inclined to the vertical axis.

The vertical axis $\dot{c}$ is therefore an axis of optical isotropy, and is called the OPTIC AXIS.

In sections at 90° *to the vertical axis* the field remains dark throughout the entire rotation of the stage.

In all other sections there is double refraction. The field is dark (extinction) at intervals of 90°, and brightest at positions diagonal to these.

The extinction directions are either parallel or symmetrical to cleavage cracks and crystal outlines. With white light, interference colors result as described, p. 165.

Orthorhombic, Monoclinic and Triclinic Crystals.

In these crystals no true optic axis exists but for light of each wave-length and for each temperature two directions of single refraction exist which are called "optic axes."

These directions usually are nearly the same for light of different colors at the same temperature.

In sections normal to an optic axis no extinction will take place, but with monochromatic light the field will maintain a uniform brightness * during rotation of the stage and with white light there may be a color tint.

* A. J. Moses, *Characters of Crystals*, p. 136.

In all other sections the field is dark every 90° and is illuminated for all other positions, most brilliantly in the positions at 45° to the extinction. If white light is used interference colors result as described, p. 165.

In *orthorhombic crystals* the *extinction directions* are always parallel or symmetrical to crystallographic edges, cleavage cracks, etc. In pinacoidal faces they are parallel to the crystal axes.

In monoclinic crystals the extinction directions are parallel or symmetrical to edges, cleavages, etc., *only when* the section is parallel to the ortho axis $\bar{b}$, but in all other zones are unsymmetrical.

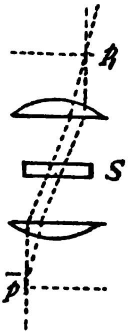
In triclinic crystals all extinction directions are unsymmetrical.

TESTS WITH CONVERGENT RAYS OF POLARIZED LIGHT AND CROSSED NICOLS.

Producing the Convergence.

If a small lens is placed above the lower nicol it will send through the crystal-plate *S*, Fig. 296, rays converging towards its focus. Each direction in which rays are sent is traversed by a minute bundle of parallel rays, and therefore for each direction the same extinction and interference phenomena occur as were described for parallel light.

FIG. 296.



In other words each direction yields a spot p_1 in the field, dark four times and of a specific color at all other times, and from all these spots combined there results an "*interference figure*" or picture, the shape, brightness and tints of which depend upon the structure of the plate *for all the directions* traversed by the rays.

Using the Microscope for Convergent Light Effects.

Convergent light tests are made with the polarizing microscope, Fig. 292, by using a high power objective and placing a small convergent lens over the lower nicol. The section is focused with the upper nicol out then this is pushed in, the lower nicol raised as high as possible by the lever *h*, the eye piece removed and the interference figure may be seen by looking down the tube.

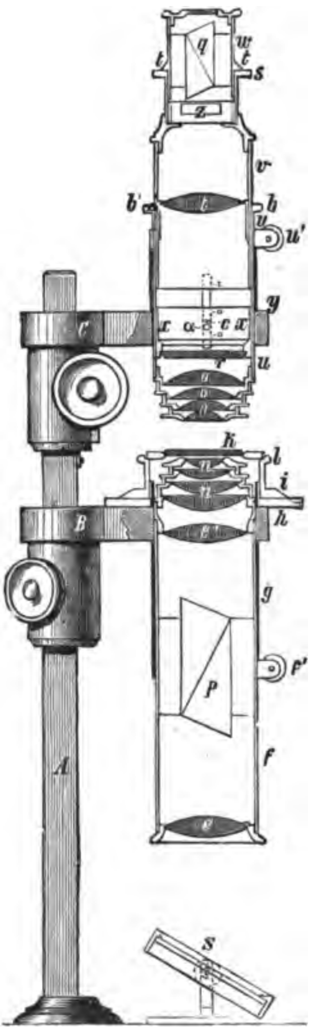
In instruments of greater complexity the eye piece may be retained and the interference figure made visible by an additional lens inserted in the microscope tube.

The Norremberg Polariscope.

Larger and finer figures are obtained with the Norremberg polariscope, Fig. 297: *e*, *e'* are collecting lenses on each side of the polarizer, above *e'* are four plano-convex lenses, *n*, forming the condenser and just over these the stage *h*.

In a separate tube system above are the objective, composed of four similar plano-convex lenses *o*, and at their focal plane the glass plate *r*, on which a cross and a scale are marked; the image there formed is magnified by *t* and viewed through the analyzer *q*.

FIG. 297.



Isometric Crystals.

As with parallel light *any* section will transmit vibrations in any direction with equal facility, the light from the polarizer will be transmitted without change and will all be shut out by the analyzer. *That is, the field will remain dark whatever the position of the plate, both in parallel and convergent polarized light.*

Tetragonal and Hexagonal (Uniaxial) Crystals.

In the absence of prepared sections, thin wulfenite crystals and cleavages of brucite may be used.

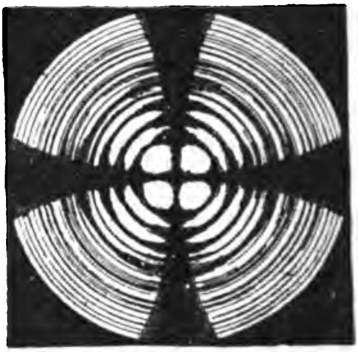
In sections at right angles to the vertical axis*, *c*, which, as explained, page 167, is an *optic axis*, there will always appear a dark cross, the arms of which intersect in the center of the field, and remain parallel to the vibration directions (diagonals) of the nicols during rotation of the section.

* In thick sections of quartz or cinnabar the arms of the cross do not reach the center and the central circle, when white light is used, is colored a tint due to the rotation of the plane of polarization.

Any ray will vibrate either in or at 90° to a plane through the ray and the optic axis. Hence the rays transmitted parallel to the vibration planes of the crossed nicols have their vibrations in these planes and are totally extinguished. As the stage is rotated successive rays come into these positions maintaining the same effect.

Uniaxial Crystals with White Light.

FIG. 298.



The interference figure, if colored at all, will show colored circles around the center of the cross.

For the phase difference increases as the angle of the rays with the optic axis increases, and as ALL RAYS at any given angle have the same phase difference, the colors which result are in circles.

The reasons are as for parallel light. For light of each wave-length destructive interference takes place at those points at which the "Retardation Δ" is equal to one, two or three, etc., wave-lengths of the light, p. 164. Therefore, that particular color is extinguished in circles around the center of the cross at distances apart varying with the crystal and the thickness of the crystal section.

In sections of the same mineral the thicker the section the closer the rings, while in sections of different minerals but equal thickness the greater the value of the double refraction, $(n' - n)$, p. 165, the closer the rings.

Optically + and — Uniaxial Crystals.

If the quarter undulation mica plate, p. 166, is inserted *between* the nicols and above the crystal section it will break up the interfer-

FIG. 299.

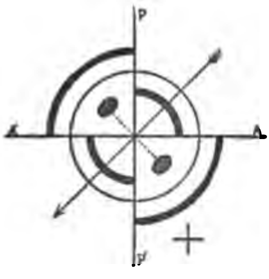
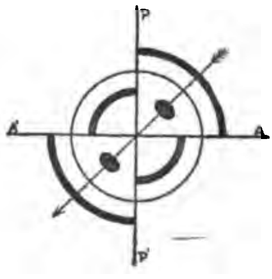


FIG. 300.



ence figure differently in different crystals. The color circles will become four quadrants and instead of the black center there will be two black dots. The effects in so-called "positive" and "negative" crystals are shown in Figs. 299 and 300. The corresponding

signs + and − are suggested by the relative positions of the dark flecks and the arrow showing the direction c of the test plate.

When no colored rings are to be seen it is more convenient to insert a gypsum red of first order plate, p. 167, with its direction a in diagonal position, the effect being that "blue quadrants" correspond in position to the black flecks. This determination must be made in white light.

In Orthorhombic, Monoclinic and Triclinic (Biaxial) Crystals.

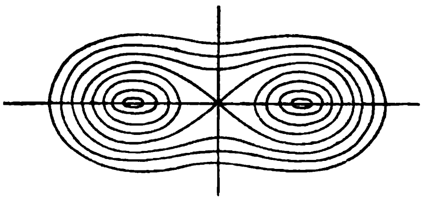
In the absence of prepared sections, cleavages of mica and topaz yield good figures.

In orthorhombic, monoclinic and triclinic crystals no direction exists which corresponds to the optic axis of hexagonal and tetragonal crystals, but at any given temperature there are two directions *for each color of light* which are directions of single refraction. These directions are therefore to this extent like the optic axis of hexagonal and tetragonal crystals and give the name "Biaxial" to the crystals. The line which bisects the acute angle between these "axes" is called the *Acute Bisectrix* or* Bx_a.

Sections at 90° to Acute Bisectrix Between Crossed Nicols in Convergent White Polarized Light.

The crystal sections most frequently studied are cut at 90° to the Bx_a for yellow light at ordinary room temperature. In such sections the points of emergence of the optic axes are black,† and

FIG. 301.



when the line connecting these is parallel to the diagonals of the nicols, there is a sharp dark band, Fig. 301, joining the axes and another somewhat thicker, lighter band at right angles to the first

* Similarly the line bisecting the obtuse angle between the axes is known as the Obtuse Bisectrix, Bx_o.

† This assumes the optic axes for different colors to emerge approximately at the same points. If there is notable "dispersion" the black bands and hyperbolæ may be rainbow hued as with titanite.

and midway between the axes. These lines are due to the shutting out of rays vibrating parallel to the nicols.

If the section is turned, other rays vibrate parallel to the nicols and the straight dark lines seem to dissolve into hyperbolæ, Fig. 302, the branches of which rotate in the opposite direction to the rotation of the stage. The convex side of each is always toward the other branch.

FIG. 302.

Color Rings. — If any color is shown it is in curves made up of the points of emergence of all rays with the same phase difference. These curves are not circles.

That is for each color the points corresponding to $\Delta/\lambda = 1$ will together form a ring around each axis and similarly for values of 2, 3, 4, etc., until the pair corresponding most nearly to the value Δ/λ for the center of the field unite at or near the center to a cross loop or figure eight around both axes and subsequent rings form lemniscates around this as in Fig. 302.

There is no change in shape during rotation of the stage. If Δ/λ for the center is less than unity even the first ring will surround both axes.

With sections of the same mineral the thicker the section the closer together are the rings, and with sections of different minerals, but equal thickness, the greater the "double refraction," p. 165, the closer together the rings.

Optically + and – Biaxial Crystals.

If the distance between the axial points in the interference figure obtained from a section at 90° to the acute bisectrix,* is small, the quarter undulation mica plate may be used as described, p. 170, for uniaxial crystals.

If the distance between the axial points is large, the interference figure is placed with the line joining the axial points in diagonal position, as in Fig. 302, and the quartz wedge, p. 165, is gradually inserted with the direction c parallel to this line. If the crystal is *positive* the rings around each axis will *expand*, moving toward the

* To determine the acute bisectrix it may be necessary to first measure the axial angle. Ordinarily the interference figure in a section normal to the obtuse bisectrix will not come within the limits of the field.

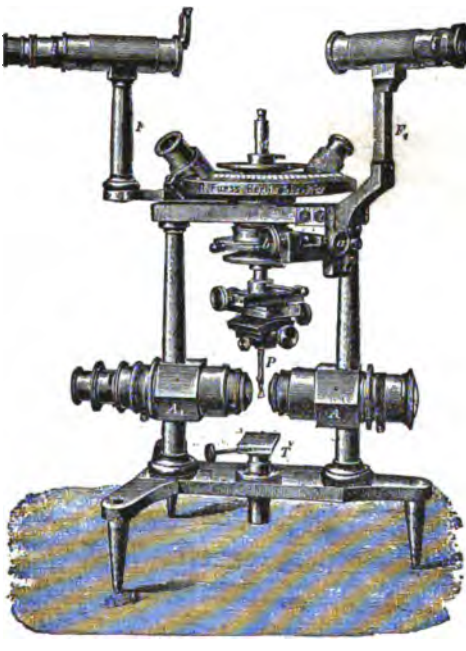
center and corresponding rings will merge in one curve. If the crystal is ***negative*** the rings will ***contract*** and increase in number, the change increasing with the thickness of wedge interposed.

In a section ***normal to the obtuse bisectrix*** these results are all reversed.

Determination of the Angle Between the Optic Axes.

The axial angle may be determined approximately in any polariscope, or suitably equipped microscope, by measuring the distance d from the center to either hyperbola with a micrometer eye-piece, or better by averaging the distances to both. Then $\sin E = d/C$,

FIG. 303.



or $\sin V = d/\beta C$, in which C is a constant for the same system of lenses and is determined once for all by using a crystal of known axial angle.

For instance if in a mica $2E = 91° 50'$ and $d = 41.5$ divisions on the scale, then $C = d/\sin E = 57.78$ for that combination of lenses.

The axial angle is $2V$, and $2E$ is the so-called apparent angle.

A more exact measurement may be made by placing at P, Fig.

303, between the lenses of a horizontal polariscope* a section cut at 90° to the acute bisectrix. The vibration directions of the nicols of the polariscope are crossed at 45° to the horizon, so that when the line connecting the axial points is horizontal the interference figure shows the hyperbola and not the cross. The section is centered so that a line in it is the axis of revolution; and so that the axial points of the interference figure remain on the horizontal cross hair during revolution.

The crystal is then revolved by the horizontal circle until the two arms of the interference hyperbola are successively made tangent to the vertical cross-hair, the positions being read on the circle. The difference between the two readings is the apparent angle $2E$, and this is frequently the angle recorded. It is always larger than the true angle, $2V$.

To find the True Angle from the Apparent Angle.

A second measurement may be made of the apparent angle in a plate normal to the *obtuse* bisectrix. Denoting this by $2E'$ the relation is $\tan V = \frac{\sin E}{\sin E'}$.

Optical Distinctions Between Orthorhombic, Monoclinic and Triclinic Crystals with Convergent Light.

The interference figure, in shape and in distribution of color, is symmetrical to the planes and axes of symmetry of the system. Hence the orthorhombic figures are more symmetrical than the monoclinic and these again than the triclinic.

In orthorhombic crystals the interference figure obtained in sections parallel *to two of the three pinacoids* will be like Fig. 302, and if the figures so obtained are viewed in white light the color distribution will be symmetrical to the line joining the optic axes, to the line through the center at right angles thereto and to the central point.

In monoclinic crystals an interference figure similar to Fig. 302 will be found either in the section parallel to the clino-pinacoid or

* Fig. 303 shows the Universal Apparatus of Fuess. The centering device is precisely that described under the goniometer, p. 9. If inverted it forms with the telescopes F_1 and F a goniometer.

When used for axial measurements, the crystal stand is replaced by the pincers P which clip the crystal plate. The optical portion inserted at A and A_1 is the same Norremberg arrangement of nicols and lenses which is shown in Fig. 297, but turned so that the vibration directions of the nicols cross at 45° to the horizon.

in one of two sections normal to this. In white light the distribution of color of this figure will never be symmetrical to *two* lines as in the orthorhombic, but will be symmetrical either to the line joining the axial points, or to the line normal to these, or to the central point.

In triclinic crystals in white light, the distribution of color in the interference figure is without symmetry to any line or point.

ABSORPTION AND PLEOCHROISM.

Light during transmission through a crystal is in part absorbed and in most instances diminishes steadily in intensity as the distance traversed increases.

With white light the different component colors are often absorbed at different rates, giving color tints due to the combination of the remaining colors.

In Isometric Crystals.

A section of any given thickness will transmit the same color-tint whatever the direction in which the crystal may be cut.

In Doubly Refracting Crystals.

In all doubly refracting crystals the ordinary and extraordinary rays transmitted in any given direction may be differently absorbed.

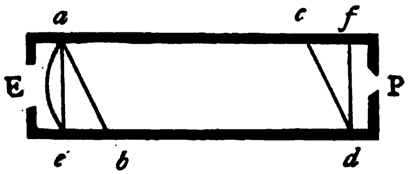
Thus, if an apparently transparent prism of tourmaline is placed on the stage of a polarizing microscope with the upper nicol out and the stage is turned, the prism will darken and will become opaque when its length is at 90° to the vibration direction of the lower nicol, but will be transparent when the length is parallel to this vibration.

In other instances colors result from partial absorption of certain tints. As before the absorption varies with the vibration direction, so that, again using a polarizing microscope with the analyzer out, the color varies as the stage is turned and the maximum color differences are obtained when the extinction directions of the crystal section coincide with the vibration plane of the polarizer.

For instance, in iolite, transmission parallel the $\dot{c}$ axis gives a gray and a blue, transmission parallel the $\bar{b}$ axis gives a gray and a yellow, and transmission parallel the $\breve{a}$ axis gives a blue and a yellow. In other words the light vibrating parallel $\breve{a}$ is gray, parallel $\bar{b}$ is blue, parallel $\dot{c}$ is yellow.

The colors of the ordinary and extraordinary rays may be *contrasted* side by side by means of a "dichroscope," consisting, Fig. 304, of a rhomb of calcite, in which *ab* and *cd* are the short diag-

FIG. 304.



onals of opposite faces. To these faces glass wedges *aeb*, *dfc*, are cemented and the whole encased. The section is placed at *P* and turned until the two images show their maximum difference in color, the light from the substance passes through a rectangular orifice, a double colored image of which is seen by the eye at *E*.

CHAPTER XVIII.

THE THERMAL, MAGNETIC AND ELECTRICAL CHARACTERS.

THE THERMAL CHARACTERS.

Transmission of Heat Rays.

HEAT rays may be reflected, refracted, doubly refracted, polarized and absorbed, and it is possible, though difficult, to determine a series of thermal constants for crystals.

Conductivity.

The rapidity with which heat is conducted in different directions in a crystal is in accordance with its symmetry. This may be shown on any face or cleavage surface as follows:

(*a*) The surface is breathed upon, quickly touched by a very hot wire, dusted with lycopodium powder, turned upside down and tapped carefully. The powder falls from where the moisture film has evaporated, but adheres elsewhere, giving a sharply outlined figure. The entire operation should take less than three seconds.

(*b*) The surface is coated with a mixture of three parts elaidic acid and one part wax, brought into contact with a hot wire, and the temperature maintained until the wax has melted around the wire. The boundary of the melted patch is visible, after cooling, as a ridge.

A *circle* indicates either an *isometric* crystal or a basal section of a hexagonal or tetragonal crystal. All other sections yield ellipses varying in eccentricity and in position of axes.

Expansion.

When a crystal is uniformly heated, directions crystallographically alike expand in the same proportion, but directions unlike do not.

The expansion may be accurately measured for any direction but the methods involve apparatus of great precision and cost.

Change of Crystal Angles Produced by Expansion.

An isometric crystal uniformly heated expands without change of angles. In all other systems the expansion varies with the direction and certain angles are changed (sometimes several minutes for 100° temperature alteration. For instance, the calcite rhombohedron angle is lessened 8′ 37″). The zone relations and indices are never changed.

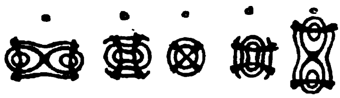
These changes may be measured with accurate goniometers and the relative expansions calculated.

Change of Optical Characters Produced by Expansion.

The expansion of a crystal changes the indices of refraction for different directions. With isometric crystals the index may become either larger or smaller. With tetragonal and hexagonal crystals the principal indices of refraction may alter unequally. The interference figure will also alter and for a particular temperature will disappear.

In orthorhombic, monoclinic and triclinic crystals the interference figure may undergo even more striking changes. For instance, Fig. 305 represents such a series in gypsum with yellow light

FIG. 305.



for which at 20° C, the axial angle is 92° (Fig. *a*), at 100° C. is reduced to 51° (Fig. *b*), at 134° C. is zero (Fig. *c*), and for still higher temperatures the optic axes pass into a plane at right angles to their former position (Figs. *d* and *e*).

THE MAGNETIC CHARACTERS.

Magnetism. — A few iron-bearing minerals attract the magnetic needle or are attracted by a steel magnet. Of these minerals, magnetite, pyrrhotite and platinum will themselves occasionally act as magnets.

Para- and Diamagnetism.

Any substances will be either attracted or repelled in some degree in the field of a strong electromagnet.

If a rod of the substance is suspended by a fiber so as to swing horizontally between the poles of an electromagnet, the rod is *paramagnetic*, if pulled into "*axial*" position with its ends as near the poles of the magnet as possible, and, is *diamagnetic*, if pushed into an "*equatorial*" position with its ends as far from the magnetic poles as possible.

Crystals are more strongly magnetized in certain directions than in others.

ELECTRICAL CHARACTERS.

Frictional Electricity.

All minerals are electrified by friction but the + or — character may vary in varieties of a species and even in the same specimen.

If a light, horizontally-balanced needle terminating in small balls, is electrified, either positively by bringing near a rod of electrified sealing wax, or negatively by touching with the rod, an electrified mineral will attract or repel the needle according as it has opposite or similar electricity.

Electrical Conductivity.

All minerals conduct, but practically, conductivity is limited to the metals, some metalloids, most sulphides, tellurides, selenides, bismuthides, arsenides and antimonides, some of the oxides, and, at higher temperature, a few haloids.

If a rod is introduced into a weak current, the strength of which is varied by resistances and the deviation observed in a galvanometer, the results will vary for different minerals between very wide limits dependent upon the constitution of the chemical molecule more than upon the crystalline structure.

Thermo-electricity.

If two conducting minerals are made part of a metallic circuit, heating or cooling the junction will develop * an electric current, the strength of which will depend upon the change of temperature and upon the minerals used.

Among metals a series based upon the strength and direction of the current extends from bismuth at the positive end to selenium at the negative end. The position of minerals in the series may be practically determined.

A current is developed by coupling two rods cut from different directions in the same crystal and in the case of pyrite opposite currents are produced by coupling copper with the + or — pyritohedron.

Pyroelectricity and Piezoelectricity.

Poorly conducting crystals which have not a center of symmetry if altered in volume either by a temperature change or by pressure will frequently accumulate positive and negative charges of electricity at different points.

PYROELECTRICITY. — Usually the crystal is heated † in an air-bath to a uniform temperature, then drawn quickly once or twice through an alcohol flame and allowed to cool. During the cooling of the crystal positive charges collect at the so-called *antilogue* poles, and the negative charges at the *analogue* poles,‡ and may be distinguished by their effect on other electrified bodies. For

* The possible cause of currents in metallic veins.

† If heating injures the crystal it may be cooled from room temperature by a freezing mixture.

‡ With rising temperature these are reversed.

instance, a cat's hair rubbed between the fingers becomes positively electrified and is attracted by the analogue pole and repelled by the antilogue pole.

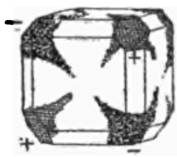
Kundt's Method. — The positive and negative poles may be distinguished by blowing upon the cooling crystal a fine well dried * mixture of equal parts of powdered sulphur and red oxide of lead. The nozzle of the bellows is covered by a fine muslin net. By mutual friction in passing through the sieve, the sulphur is negatively electrified and is attracted by the antilogue poles coloring them yellow while the minium is positively electrified and is caught by the analogue poles, coloring them red. The dust should fall evenly and the bellows be held far enough away to prevent direct action of the blast.

Figs. 306, 307 and 308 show crystals of tourmaline, calamine and boracite respectively, the darker dotted portions representing the

FIG. 306.

FIG. 307.

FIG. 308.



accumulation of minium at the analogue poles and the hatched portions the accumulations of sulphur at the antilogue poles.

If the crystals had been dusted during the heating the analogue poles would have been coated with sulphur and the antilogue poles with minium.

In PIEZOELECTRICITY the charges are developed by pressure, for instance, calcite pressed between the fingers becomes positively electrified, tourmaline compressed in the direction of the vertical axis develops a positive charge at the antilogue end and a negative charge at the analogue end or precisely the charges which would result from cooling a heated crystal.

The charges are detected in the same way as the pyroelectric charges.

* Dry over H_2SO_4 in a vessel from which the air has been partially exhausted.

CHAPTER XIX.

CHEMICAL COMPOSITION AND REACTIONS.

As has already been stated, minerals are distinguished from rocks by something of regularity in their chemical structure. Their chemical composition is their most important characteristic whether for identification or classification. The only clear conception of the relationship between minerals is based upon the elements of which they are composed, but while they may be best considered as derived from definite chemical types they are very far from being of definite and invariable composition and it is often difficult to represent the results of analysis by an exact formula. This is readily understood when the laws of isomorphism and the conditions underlying the formation of minerals are studied.

ISOMORPHISM.

Certain chemical substances having a distinct similarity in their molecules and presenting a close resemblance in their reactions crystallize in forms which in the regular system are identical and in the other systems are so closely related as to require, at times, special care in angle measurement to recognize any difference. Such substances are said to be isomorphous when they can replace each other in the same crystal or crystallize together to form homogeneous mixed crystals.

Compounds which are isomorphous generally have the same number of atoms in their molecules and close similarity in their structure. Replacing isomorphous elements usually have the same valency and are closely related chemically.

The carbonates

Aragonite, $CaCO_3$		Calcite, $CaCO_3$
Strontianite, $SrCO_3$		Siderite, $FeCO_3$
Witherite, $BaCO_3$	and	Smithsonite, $ZnCO_3$
Cerrussite, $PbCO_3$		Magnesite, $MgCO_3$
		Rhodochrosite, $MnCO_3$

form two characteristic isomorphous groups, the first orthorhombic and the second rhombohedral.

Such *isomorphous compounds are capable of mixing in varying proportions to form homogeneous crystals*, as Mitscherlich has shown and they cannot, therefore, be separated by ordinary crystallization, as the analogous compounds crystallize together, and the crystals formed show by analysis the most varied quantitative proportions of the isomorphous substances originally present. Not only may mixed crystals be formed by the intermingling of different members of isomorphous groups but individuals may combine in molecular proportions to form double salts like dolomite, $CaCO_3$, $MgCO_3$, which has physical properties essentially its own. The physical properties of homogeneous mixed crystals, such as specific gravity, refractory index, etc., are continuous functions of the composition and in fact such crystals behave so much like intimate mechanical mixtures or mixed liquids that they are frequently spoken of as solid solutions. Such mixtures, as a whole, cannot appear to follow the law of definite proportions but on careful study of their constituents they can all be resolved into groups of perfectly definite composition.

For purposes of convenience such minerals are often considered as formed by the replacement of one element or radical by another isomorphous with it rather than as a mixture of different individual molecules. Mutually replaceable isomorphous elements and radicals occurring in minerals as given by Miers * are as follows:

H, K, Rb, Cs, Na, Li, NH_4, in the haloids, nitrates, phosphates and silicates.

F, Cl, Br, I, OH, in the haloids, phosphates and silicates.

Au, Ag, Hg, Cu′, Tl, in the sulphides and sulpho-salts.

Be, Zn, Mg, Fe, Mn, Cu″, Ca, in the phosphates and silicates.

Mg, Zn, Fe, Mn, Ni, Co, in the sulphates.

Ca, Ba, Sr, Mg, Pb, Zn, Fe, Mn, in the carbonates and sulphates.

Fe, Ni, Co, Mn, Zn, Cd, in the sulphides and sulpho-salts.

Al, Fe‴, Cr, Mn‴, in the oxides, aluminates, phosphates and silicates.

Si, Ti, Zr, Sn, Pb, in the oxides and silicates.

S, Se, Te, in the sulphides and sulpho-salts.

P, V, As, in the phosphates, etc.

As, Sb, Bi, in the oxides, sulphides and sulpho-salts.

Mo, W, in the oxides, molybdates, etc.

Y, Er, Ce, La, Di, in the haloids, phosphates, silicates, etc.

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* Miers, *Mineralogy*, p. 217.

The principle of isomorphic replacement is well illustrated in the garnets which have the class formula

$$R_3''R_2'''(SiO_4)_3$$

in which R″ stands for any combination of the isomorphous divalent atoms Ca, Mg, Fe″, Mn taken three at a time and R‴ denotes any combination of the isomorphous trivalent atoms Al, Cr or Fe‴.

Therefore while the typical species

Grossularite,	$Ca_3Al_2(SiO_4)_3$
Pyrope,	$Mg_3Al_2(SiO_4)_3$
Almandite,	$Fe_3Al_2(SiO_4)_3$
Spessartite,	$Mn_3Al_2(SiO_4)_3$
Andradite,	$Ca_3Fe_2(SiO_4)_3$
Uvarovite,	$Ca_3Cr_2(SiO_4)_3$

have the formulas assigned to them when pure they are in fact seldom found on analysis to more than approach these formulas since their divalent element may be replaced by any one of the isomorphic group Fe″, Mg, Mn, or Ca while their trivalent element may be any combination of Fe‴, Al or Cr. Accordingly garnets vary through all combinations of color, with wide divergence of composition. Still their crystalline forms are identical and their composition can be expressed as of a definite type. This variability of composition can be due to two causes, (1) a replacement of elements within the molecule or (2) a crystalline mixture of different molecules of the group which in the case of the garnets is generally homogeneous.

Homogeneity is not, however, an essential of crystals for the center of a crystal may vary greatly from the outer surface or the two ends be different in color, as is so frequently seen in the tourmalines, but the different kinds of molecules which have crystallized together must be isomorphous.

Most minerals are isomorphic mixtures. They have, as a rule, been formed by crystallization either from solution, from fusion, or more rarely by the condensation of sublimed vapors. Some, as limonite, have been formed by a process of sedimentation but such are uncrystallized, and are generally quite impure. Others are the results of alteration from atmospheric agencies and frequently contain in the same specimen the original mineral and its alteration product.

Whenever a mineral has crystallized from solution or from fusion it is always more or less modified by the elements which may be present and which are foreign to its own typical structure. Three cases present themselves:

1. If the liquid contains no other substance than the compound of which the mineral is made then it crystallizes out in a state of purity and is as definite in its composition as any compound made in the laboratory.

2. If the liquid contains several other substances but none which is isomorphous with the compound of which the mineral is made, it may crystallize in all degrees of purity, tending always to form crystals of definite composition but the composition of the mass varying with the degree with which the liquid is saturated with the foreign substances. This gives rise usually to a series of fractional crystallizations especially apparent in beds of rock salt or in mica and orthoclase veins. If the substances are in solution that one is first deposited whose saturation point is first reached by any process of concentration, the others following in their respective order. Where the case is one of fusion those substances with the highest melting points will tend to crystallize out first and in a state of comparative purity.

3. The liquid may contain two or more isomorphic compounds in which case the resulting mineral will contain each of these substances usually in about the relative proportion in which they were present.

Isomorphic compounds are generally salts of the same acids with the metallic elements different, but this is not always the case, for acid radicals may also replace each other.

Composition and Formula.

It will thus be seen that many factors besides the results of analysis must be taken into consideration in giving a formula to any mineral. When, however, the errors of calculation, arising from the impurities and from the replacing of certain elements by others of different atomic weight but isomorphous with them, are eliminated, it is generally possible to assign a typical formula to the species. The difficulty becomes greater when the polysilicates and some other complicated minerals are studied and in no case must the formula for the species be considered as absolutely invariable for the individual. The results of alteration through atmospheric

agencies, infiltration of water, etc., tend at times to so alter the individual that its composition varies widely from the type while at times this alteration is carried on so regularly and so far that new species of quite definite composition are formed. In expressing the composition by formulas the ordinary chemical symbols are used. The letter R is used to represent a varying group of isomorphic or equivalent elements, and it may have the valency of these elements designated by dots above and to the right of the letter. When two elements as (Fe.Mg) are placed in parenthesis with a period between it, indicates that the two replace each other in all proportions in the different individuals of the species. True molecular formulas can not be given to minerals for they are volatile or soluble only in rare instances. The symbols therefore represent little more than the relative proportions of the elements expressed in equivalents of their atomic weights, *i. e.*, empirical formulas. Most minerals can, however, be considered as derived from known or hypothetical inorganic acids, and in many instances they have been artificially produced in the laboratory as salts of these acids. Thus calcite, $CaCO_3$, is a derivative of carbonic acid, H_2CO_3; fluorite, CaF_2, of hydrofluoric acid, HF; zircon, $ZrSiO_4$, of orthosilicic acid, H_4SiO_4, etc. These derivatives may be normal, acid, or basic salts. In normal salt all of the hydrogen of the acid has been replaced by a metallic element or elements. In acid salts, which are rare except perhaps in silicates, only part of the hydrogen has been replaced. In basic salts more metallic atoms or radicals are present than are equivalent to the hydrogen of the acid. Minerals may therefore be classified into various types according to their derivation.

Types.

The most prominent types found among minerals are as follows:

1. The ELEMENTS, as Au, Ag, Cu, Sb, C, S. These are frequently alloyed with other elements as copper with silver, sulphur with selenium, etc.

2. The OXIDES and HYDROXIDES for which water, H_2O, serves as a type, as cuprite, Cu_2O, brucite, $Mg(OH)_2$. It is not necessary that the hydrogen atom or atoms be replaced by a single element. This replacement may be by a group of elements as in diaspore, AlO(OH) or on the other hand the oxygen may be partially replaced by sulphur as in kermesite, Sb_2S_2O.

3. The SULPHIDES, derivatives of H_2S, and to a less extent their analogues the SELENIDES, TELLURIDES, ARSENIDES and ANTIMONIDES, as galenite, PbS, clausthalite, PbSe, hessite, Ag_2Te, niccolite, NiAs. The hydrogen may be replaced by more than one element as in chalcopyrite, $CuFeS_2$, or the sulphur may be partially replaced by arsenic as in arsenopyrite, FeAsS, by antimony as in ullmannite, NiSbS, and also by selenium and by tellurium, but to a less extent and with smaller tendency to form distinct species.

4. The CHLORIDES, derivatives of HCl, and to a less extent their analogues the FLUORIDES, BROMIDES, and IODIDES as halite, NaCl, fluorite, CaF_2, bromyrite, AgBr, iodyrite, AgI.

More than one metal may replace the hydrogen as in the double fluoride cryolite, Na_3AlF_6, and chlorides, bromides, iodides or fluorides may crystallize together as in embolite, Ag(Cl.Br).

5. NITRATES, derivatives of HNO_3, as nitre, KNO_3; soda nitre, $NaNO_3$; isomorphic or basic modifications are rare.

6. CARBONATES, derivatives of H_2CO_3, as calcite, $CaCO_3$; sider-te, $FeCO_3$, etc. Isomorphic combinations are common. The carbonates of Zn, Fe, Mn, Ca and Mg are isomorphous, and also the carbonates of Ca, Ba, Sr and Pb. Consequently, minerals containing various combinations of these carbonates are found. Many basic salts of carbonic acid also occur, as malachite, $Cu_2(OH)_2CO_3$; azurite, $Cu_3(OH)_2(CO_3)_2$. Carbonates are also frequently found containing water of crystallization as natron, $Na_2CO_3 + 10H_2O$. In a few instances a carbonate and a halogen salt crystallize together as in phosgenite, $Pb_2Cl_2CO_3$.

7. SULPHATES, derivatives of H_2SO_4, as anhydrite, $CaSO_4$; barite, $BaSO_4$, etc. Isomorphic combinations are more common than simple sulphates. Among double salts may be noted sulphates containing two or more metals, as glauberite, $Na_2SO_4.CaSO_4$; those containing a sulphate and chloride, as kainite, $MgSO_4.KCl + 3H_2O$. Basic sulphates are also numerous, as brochantite, $Cu_2(OH)_2SO_4$.-$2Cu(OH)_2$, and some individuals of any of the previous types crystallize with water of crystallization, as copiapite, $Fe_2(FeOH)_2(SO_4)_5 + 18H_2O$.

8. CHROMATES, derivatives of H_2CrO_4, as crocoite, $PbCrO_4$, and derivatives of $HCrO_2$, as chromite, $FeCr_2O_4$. These are the two important mineral chromates. Two or three rare basic compounds are also known.

9. MOLYBDATES, derivatives of H_2MoO_4, as Wulfenite, $PbMoO_4$, which is the only important natural molybdate.

10. TUNGSTATES, derivatives of H_2WO_4, as scheelite, $CaWO_4$. Tungstates also are rare. One or two isomorphic combinations are known, as in wolframite, $(Fe.Mn)WO_4$, powellite, $Ca(Mo, W)O_4$.

11. BORATES, derivatives of HBO_2, H_3BO_3 or of $H_2B_4O_7$, as sassolite, H_3BO_3; borax, $Na_2B_4O_7 + 10H_2O$. Metaborates are rare. Ulexite, $CaNaB_5O_9 + 6H_2O$, may be considered as a molecular combination of $CaB_4O_7 + NaBO_2$, while colemanite, $Ca_2B_6O_{11} + 5H_2O$, would consist of $CaB_4O_7 + Ca(BO_2)_2$. Most natural borates contain water of crystallization, and a few basic combinations are found.

12. ALUMINATES, derivatives of $HAlO_2$, as spinel, $Mg(AlO_2)_2$; chrysoberyl, $Be(AlO_2)_2$. The aluminates are isomorphous with the ferrates and metachromates, consequently the Al may be partially replaced by Fe or Cr, while, on the other hand, the common aluminates are themselves isomorphous, and the Mg, Fe, Zn and Mn salts replace each other in their characteristic spinels to a limited extent.

13. PHOSPHATES, derivatives of H_3PO_4, as vivianite, $Fe_3(PO_4)_2 + 8H_2O$. By far the majority of mineral species of phosphates are either isomorphic modifications or basic salts, both with and without water of crystallization. Simple phosphates may crystallize together, as in triphylite, $Li(Fe.Mn)PO_4$. Phosphates may crystallize with chlorides and fluorides, as in apatite, $Ca_5(Cl.F)(PO_4)_3$. Basic salts may be simple, as in turquois, $Al_2(OH)_3PO_4 + H_2O$, or may contain several metals, as in lazulite, $(Mg.Fe.Ca)Al_2(OH)_2(PO_4)_2$.

14. ARSENATES, derivatives of H_3AsO_4, form compounds very similar to the phosphates in molecular structure, as scorodite, $FeAsO_4 + 2H_2O$, a hydrous ferric arsenate; mimetite, $3Pb_3(AsO_4)_2 + PbCl_2$, a combination of the isomorphic arsenate and chloride; olivenite, $Cu_2(OH)AsO_4$, a basic copper arsenate. Also a few rare antimonates.

15. SULPHARSENITES, derivatives of H_3AsS_3 and their analogues the SULPHANTIMONIDES, are frequently classed with the sulphides but are more properly derived from hypothetical acids similar to H_3AsO_3, etc., in which the oxygen is replaced by sulphur, as proustite, Ag_3AsS_3; pyrargyrite, Ag_3SbS_3.

16. VANADINATES, COLUMBATES and TANTALATES, derivatives of H_3VO_4, $HCbO_3$ and $HTaO_3$. The chief vanadinates are vanadinite, $3Pb_3(VO_4)_2 + PbCl_2$, a molecular combination of lead vanadinate and chloride, and descloizite (Pb.Zn) (Pb.OH)VO_4, a basic lead vanadinate containing zinc. The most important natural columbate is the mineral columbite, $Fe(CbO_3)_2$. The most prominent tantalate is tantalite, $Fe(TaO_3)_2$.

16. SILICATES. — By far the largest number of minerals known fall under this subdivision. They may generally be considered as derived from orthosilicic acid, H_4SiO_4, metasilicic acid, H_2SiO_3, or some one of the hypothetical polysilicic acids, $H_2Si_2O_5$, $H_4Si_3O_8$, $H_8Si_3O_{10}$ or $H_6Si_2O_7$. These polysilicic acids may be considered as derived from one or more molecules of orthosilicic or metasilicic acid by the elimination of water. Isomorphic combinations are the rule, and these combinations are at times so complicated that it is almost impossible to give even a typical formula to the species. Basic and acidic salts are common, but the silicates do not show as great tendency to crystallize with water of crystallization as is possessed by some of the other classes of compounds. Those which do contain water of crystallization are commonly considered in a class by themselves, on account of their many resemblances. The basic elements most commonly replacing each other are Ca, Mg, Fe, Zn and Mn; Na, Li and K, and Al, B, Cr and Fe. The silicon is itself sometimes partially replaced by Al, as in anorthite, or by Ti, as in titanite.

Calculation of Formulas.

In expressing the composition of a mineral by a formula we have only the atomic weights of its component elements and the results of analysis from which to calculate. Hence the formulas given do not of necessity express the structure of the molecule, but only the composition ratio. In fact, the symbols adopted are always the simplest which can express the proportions shown by analysis to exist between the atoms and which satisfy their valences. The true molecular formulas are probably always some unknown multiple of these symbols. For the purposes of mineralogy, however, the composition formulas are sufficient.

An example may make this point clearer. A very pure specimen of beryl gave the following results on analysis:

	Per cent.
BeO, ...	14.01
Al_2O_3,.	19.26
SiO_2, ...	66.37

The sum of the atomic weights for each group is:

$$BeO = 25.$$
$$Al_2O_3 = 102.$$
$$SiO_2 = 60.$$

The results of analysis represent the proportion in which the groups are present in the molecule. Consequently, the relation between the number of groups must be:

Percentage Composition.		Atomic Weights.		Proportionate Number of Groups.
14.01	$\div$	25	=	.56
19.26	$\div$	102	=	.189
66.37	$\div$	60	=	1.106

Now, as fractional atoms cannot exist, our problem is simply to find the smallest number of whole groups which stand to each other in this relation, and, as $.56 : .189 : 1.106 = 3 : 1 : 6$, very nearly, therefore, the composition is represented by $3BeO + Al_2O_3 + 6SiO_2$, which may be better written $Be_3Al_2Si_6O_{18}$, or, as it at once becomes evident that the proportion between silicon and oxygen is that of a metasilicate, $Be_3Al_2(SiO_3)_6$.

It will now be found, on calculating the theoretical percentage composition of $Be_3Al_2(SiO_3)_6$, that it agrees within the limits of error with that found by analysis, and as the twelve affinities of the six SiO_3 radicals are satisfied by those of Be and Al atoms, the formula probably represents the composition of the compound. The true molecular formula is, however, $n Be_3Al_2(SiO_3)_6$ wherein n represents some whole number.

The calculation is not generally as simple as the above example might indicate. Usually, minerals contain elements which seem foreign to their true composition, and which are present either as impurities or which replace analogous elements of the true molecule. In fact, many beryls contain Cs, H_2, Na_2, Ca, or Mg replacing Be; and Fe or Cr replacing Al. Such replacing elements, if present only in small quantities, must be converted into

their equivalents of Be or Al before the calculation for formula is made.

In perhaps the majority of cases the calculation of formula is an extremely complicated matter. The silicates especially are subject to great variation in composition and in some cases it is only after examining and carefully comparing many analyses, eliminating isomorphous elements and their acid equivalents from the whole, comparing the results with calculations on hypothetical compounds, etc., that even an approximate formula can be given. Much insight is also obtained at times from artificial reproductions in the laboratory. Again when minerals are known to be closely related their analyses are carefully studied with special reference to see whether by the elimination of certain groups, which may be isomorphic, their chemical relation may not become apparent and their analogy shown by formula.

No representative formula can ever be assigned from an analysis of impure material unless the nature and extent of the impurities are known.

Clues are often obtained as to the constitution of the molecule which are entirely foreign to the percentage composition, but which materially assist in the construction of the formula. Thus H_2O, present as water of crystallization, is driven off at comparatively low temperatures, while the hydrogen of hydroxides or of acid or basic salts is usually expelled as water only under a temperature approaching that of ignition. Orthosilicates are known to be much less stable than metasilicates, and frequently are found altered to metasilicates. This fact sometimes aids in determining the formula of a compound which otherwise might be referred to either class. For instance, analytical results have been obtained for both andalusite and cyanite, which are satisfied by the formula Al_2SiO_5. This represents more oxygen than is present in any of the silicic acids, and part of the oxygen is therefore undoubtedly in combination with the aluminium. Two rational formulas now become possible, one an orthosilicate $Al(AlO)SiO_4$, the other a metasilicate $(AlO)_2SiO_3$. Andalusite is much more easily decomposable than cyanite, which is not so easily altered. The first symbol is therefore assigned to andalusite and the second to cyanite.

CHAPTER XX.

THE OCCURRENCE AND ORIGIN OF MINERALS.

OVER ninety-nine per cent. of that portion of the earth's crust which has been examined is estimated* to consist of nine elements in the following proportions:

O,	49.98	Fe,	5.08	Na,	2.28
Si,	25.30	Ca,	3.51	K,	2.23
Al,	7.26	Mg,	2.50	H,	0.94

Practically none of these exists in the free state, but combined principally as silicates and oxides and, with rarer elements, as carbonates, haloids and sulphates. The unoxidized products, such as sulphides, are comparatively rare and usually restricted to special localities.

In considering the origin of a species, it must not be forgotten that it may originate in several genetically distinct ways. Tschermak instances hematite, Fe_2O_3, in six genetic varieties:

(*a*) Rhombohedral crystals on druses with quartz and adular apparently directly from solution.

(*b*) Distorted plates in lava from volcanic emanations.

(*c*) Fibrous red hematite formed by loss of water from limonite.

(*d*) Dense red hematite in pyrite forms, evidently from pyrites.

(*e*) Dense red hematite in siderite forms, evidently from siderite.

(*f*) Dense red hematite pseudomorphic after calcite shells, evidently a precipitate by $CaCO_3$.

IMPORTANT SOURCES OF INFORMATION AS TO ORIGIN.

1. Paragenesis or The Story of Associates.
2. Alteration and Pseudomorphs.
3. Physical and Chemical Characters.
4. Synthetic Production.

Paragenesis.

The term paragenesis is used to express the relations between associated minerals. This association may be accidental, as in a conglomerate, but the association in the rock in which they were formed may reveal:

* F. W. Clarke, U. S. Geol. Survey, Bull. 78.

(*a*) *Simultaneous origin* in that sometimes one is upon or enclosed in the other and sometimes this is reversed.

(*b*) *Epigenesis* in that one species is derived from the other as in pseudomorphs and other alterations.

(*c*) *Succession* or order of deposition by relative position, as in many ore veins the sides are older than the centers, or in granite the quartz kernels took shape only after the mica and feldspar; or in porphyry where the larger enclosed crystals of quartz or orthoclase are older than the little ones which make the mass.

(*d*) *Repetition.* The same species may be repeated; for instance, the first generation in dull simple crystals, the second in bright highly modified forms, or there may be a secondary enlargement as of the quartz grains in a sandstone.

(*e*) *Related Chemical Composition.* Some element or group of elements may be common to all the associates; for instance, fluorine in the associates of cassiterite and sodium in the minerals of phonolite.

Alteration and Pseudomorphs.

Minerals are constantly undergoing alteration and each alteration tends to result in new species, because the solutions of minerals in one rock are frequently carried into contact with species and solutions from other sources and new less soluble compounds result.

Two general classes of alteration may be recognized: (1) Changes which are essentially structural, involving a molecular rebuilding but without change of material. (2) Changes which are essentially chemical involving the taking away or adding of certain elements or even the entire removal of one substance and its replacement by another.

The change may be merely superficial or may affect whole mountain masses; it may affect all minerals of a rock or only one.

The most frequently observed alterations are anhydrous silicates to hydrous silicates or sulphides to hydrous sulphates and hydrates, but changes from one anhydrous mineral to another also take place, as leucite to orthoclase, pyroxene to amphibole, calcite to aragonite.

The causes of alteration are principally the natural watery solutions, which will be discussed later, and the mountain pressures which open capillary fissures in the minerals and force the ground

waters into these. Other alterations are by action of gases and vapors at high temperatures.

Frequently minerals are found as "pseudomorphs," that is, in crystalloids, the shapes of which belong to some other mineral. In many instances these are merely casts or incrustations which prove little as to the process, but in other instances they are evidently the result of the gradual and often incomplete alteration of the original mineral and give important clues to the process of alteration and add weight to synthetic experiments by showing that in nature similar changes actually occur.

Petrifactions differ from pseudomorphs principally in that they are alterations or replacement of organic remains by mineral substances.

Physical and Chemical Characters.

Any conclusion as to the origin or mode of formation of a mineral must be in conformity with its observed physical and chemical characters. For instance, the solubility is a most important factor in determining the order of separation whether from aqueous or fusion solutions. Leucite crystals are isometric in shape, but their optical characters indicate a system of lower symmetry unless the material is heated to 433° C., the conclusion is that these isometric crystals formed above 433°. Cyanite at about the melting point of copper assumes the characters of sillimanite, hence, ignoring the effect of pressure, it formed below that temperature.

Synthetic Production of Species and of Alterations.

The successful reproduction of a mineral by a method which does not conflict with the known natural conditions is an important clue as to its probable origin,* but is not conclusive, for the same species is often made in several ways. For instance: orthoclase has been formed from fused magma, from sublimation and in the wet way and by action of solutions on leucite, and galenite has

* The production of species synthetically has several other purposes, such as settling the composition:

(*a*) By producing crystals identical in characters with those of some natural substance but avoiding the frequent natural inclusions, weathering, etc., which lead to varying analyses.

(*b*) Obtaining crystals of massive or poorly crystallized minerals.

(*c*) Obtaining simple types which are rare in nature and finding new members of series.

been formed by sublimation, by electrochemical reactions and by superheated water in a sealed tube.

On the other hand, probable theories which have not been synthetically checked are not necessarily wrong. The processes of nature are not all to be reproduced, especially the geologic periods of time.

So also the alteration of a mineral in the laboratory or even the production of pseudomorphs by possible natural methods may be of value as indicating what would happen under similar conditions maintained longer periods.

The method of synthesis chosen must conform as far as possible with the observed conditions, must employ reagents that occur in nature and are thought to have taken part in the making. Geologic time may be in part compensated for by increased pressure and a temperature of 100° to 300°; microscopic crystalline crusts must often be accepted as the equivalent of larger natural crystals.

1. THE PRIMARY MINERALS FORMED BY SEPARATION FROM FUSION SOLUTIONS.

If the earth solidified by the cooling of a mass of incandescent vapors the first crust must have floated on a hot pasty mass and must have cooled very slowly, forming crystalline rock. Whether any of this original crust still exists or not the conditions and results must have been very similar to those at the formation of the existing igneous rocks.

Below the present crust * of the earth the regularly increasing temperature and pressure indicate that at some depth everything must be fluid † and homogeneous. This fluid mass or magma under the enormous pressure due to its depth is forced up into any crack or crevice in the crust above, sometimes reaching and overflowing at the surface (volcanic rocks), at other times being forced between strata far below the surface (plutonic rocks).

In either case there is a diminished pressure and temperature, more rapid in the case of the volcanic rocks, and the composition often changes by exhalation of volatile constituents and the solidification commences.

* The very widely distributed foliated rocks known as gneiss and crystalline schist are often regarded as the original rocks, owing their foliated structure to dynamic changes, slipping, faulting, etc. Their minerals include the constituents of granite and other minerals which are the results of change.

† And deeper still again solid.

The Nature of a Magma.

This fluid magma is a fusion solution of silicates strictly analogous to an aqueous solution of several salts and the order of separation rests not upon fusibility but upon solubility. The nearly infusible leucite, for instance, in a leucite-tephrite magma goes into a solution at a little above red heat and separates at a red heat.

The Minerals which Form a Silicate Magma.

Two principles, the second a corollary of the first, seem to govern the order of separation.

1. The least soluble mineral separates first and separates only when for the existing pressure and temperature the magma is supersaturated with the substance.

2. Substances present in least amount separate first, that is, the less needed to saturate the earlier the separation. According to Lagorio the order of formation will be:

1. Accessory minerals. Principally zircon, titanite, magnetite, chromite, ilmenite, hematite, rutile, apatite, pyrite, pyrrhotite.
2. Silicates of Fe, Mg. Hypersthene, enstatite, chrysolite.
3. Silicates of (Mg, Ca). Pyroxene, amphibole.
4. Silicates of (K, Mg, Fe, Al). Biotite.
5. Silicates of (Ca, Al) or (Ca, Na, Al). Plagioclase.
6. Silicates of (Na, Al). Albite, nephelite, sodalite.
7. Silicates of (K, Al). Orthoclase, microcline, leucite.
8. Free silica. Quartz.

Essentially the same mineral species are found in the volcanic rocks and in the deep-seated or plutonic rocks, but certain facts as to genesis may be noted in each.

In the Volcanic Rocks.

The minerals were some of them formed at the release of pressure, as is indicated by the innumerable leucite crystals in the volcanic dust and swimming in the molten lava of Vesuvius and by the augite, chrysolite and labradorite in the ash of Ætna, and anorthite in the lavas of Miyake, Japan.

The formation continues after eruption, as is indicated by the fact that near the surface of a lava stream where the cooling is relatively rapid there will be much glass and minute crystals, but deeper, less glass and more and larger crystals. The larger crystals often show glassy inclusions.

In the Plutonic Rocks.

The minerals of the granites, syenites, etc., though essentially the same species as those formed in volcanic rocks, and though formed undoubtedly from similar magma, show certain differences.

They are not connected with slaggy, glassy or frothy structures, do not often contain both the earlier formed large and the later minute crystals. Glassy inclusions are rare, liquid inclusions are frequent. All these point to a slow formation under pressure and to the active participation of water in their formation.

2. CONTACT MINERALS AND MINERALS DUE TO EXHALATIONS.

Before considering the great group of minerals formed by the aid of watery solutions two minor groups may be mentioned, which are more the result of the action of the vapors which escape from the igneous rocks than of direct separation from a fused magma.

CONTACT MINERALS.

The more important group includes the minerals commonly called *contact minerals*, which are produced when an igneous rock penetrates another rock. The textures of both rocks change and new minerals form, at the contact and for some distance from it, which are undoubtedly produced by the simultaneous action of water, high temperature and pressure, very much as crystals are in the Senarmont sealed tubes. The action is essentially the formation of new compounds from the constituents of the rock which has been penetrated and to a much less extent from those of the intruding rock or of the two rocks combined. The penetration of the superheated water is perhaps the principal agent, acting both to recrystallize and as a chemical agent, and hydrofluoric and boric acid act as still more powerful agents though less in amount. The solution of fragments in the magma, changes the composition and solvent power and produces different minerals.

The contact minerals are very numerous, the principal ones being:

Meta-Silicates. — Pyroxene, wollastonite, amphibole.

Ortho-Silicates. — Garnet, vesuvianite, wernerite, chiastolite, epidote, biotite, phlogopite.

Fluo- or Boro-Silicates. — Tourmaline, topaz.

Non-Silicates. — Magnetite, pyrrhotite, rutile, graphite, fluorite.

For instance, an impure siliceous limestone in contact with an

eruptive granite would probably be converted into a granular marble containing crystals of such silicates as garnet, wollastonite, vesuvianite, wernerite, pyroxene and amphibole. If boric acid and hydrofluoric acid were given off tourmaline and topaz might form, and so on.

MINERALS DUE TO NATURAL EXHALATIONS.

Volcanoes emit steam and other vapors, often at first O and N, mixed about as in air, and a little H, and later, probably by the action of the steam and the high temperature in decomposing existing compounds, there arise vapors of HCl, SO_3, SO_2, H_2S and CO_2. These rising vapors act on the sides of the crevices and react upon each other, producing many minerals in small amounts, the principal groups being:

Sulphur by the reaction $SO_2 + 2H_2S = 3S + 2H_2O$.

Chlorides by the action of HCl on the adjacent rocks.

Sulphates by the action of SO_2 and O on the adjacent rocks.

Oxides by the decomposition of chlorides at high temperature.

Carbonates by the action of CO_2 on the oxides.

If the flowing lava passes over vegetable matter sal-ammoniac (NH_4Cl) is formed.

The existence of exhalations of steam, fluorine, boric acid and chlorine from the plutonic rocks appears to be proved by the alterations in these rocks.

Sulphur Deposits.

The massive deposits of sulphur and of the sulphides so important as ores are apparently chiefly due to H_2S, itself of volcanic origin. Spezia claims that even the Sicilian sulphur deposit, so often regarded as a reduction product of gypsum ($CaSO_4 + 2H_2O$), is a decomposition of H_2S and that the gypsum itself is due to the action of an H_2S solution on limestone.

3. MINERALS PRODUCED BY WATERY SOLUTIONS.

The minerals thus far described are, wherever they occur, subject to perpetual alteration by water and watery solutions. In addition to the rain water, the rivers, lakes and seas, the water in clefts and hollows and the comparatively freely moving waters near the surface; a so-called "ground water," is found penetrating the apparently solid rocks at great depths, filling microscopic clefts,

into which it is drawn by capillary attraction and forced by the pressure of the water column above. So general is it that almost any fragment of rock removed to a dry place exudes moisture and loses weight, and the mountain pressures by their crushing weight continually produce new capillary clefts and open new roads for the water.

The Solvent Power of Pure Water.

Distilled water at ordinary temperatures and pressures will not only dissolve large amounts of the so-called soluble salts but small amounts of almost all other substances, for instance, in per cents, gypsum 0.25, calcite 0.0025, barite 0.0002; anhydrous silicates very slightly and quartz so slightly that no numbers have yet been found to express it. Increased temperature and pressure in general increase solubility. Wöhler dissolved apophyllite crystals at 180° to 190° and 10 to 12 atmospheres pressure and by cooling they were again deposited.

The Solvent and Decomposing Effect of Carbonated Water.

The solvent power of water is greatly increased by the presence * of CO_2, pressure in this case increasing the solvent power, but increased temperature diminishing it.

For instance, water saturated with CO_2 dissolved 0.10 to 0.12 per cent. of calcite or forty times as much as pure water.

More important, however, as bearing upon the alteration of silicates, is that water containing carbonic acid or alkaline carbonates in solution will decompose many silicates † forming carbonates with some of their bases and either free silica or a soluble alkaline silicate and often leaving behind silicates of aluminium, iron or magnesium.

The Effect of Other Substances in Water.

Free oxygen may oxidize sulphides and arsenides and further oxidize oxides or even drive out CO_2, for instance forming hematite from siderite, $4FeCO_3 + 2O + 3H_2O = 2Fe_2O_3 + 3H_2O + 4CO_2$.

Organic materials in water may cause reduction to lower oxides or native metals, and of alkaline sulphates to sulphides, which then

* The rain passing through the atmosphere absorbs about 1.25 per cent. nitrogen, .65 per cent. oxygen and .03 per cent. of carbon dioxide.

† For example, tremolite may be converted into talc and calcite, $CaMg_3Si_4O_{12} + CO_2 + H_2O = H_2Mg_3Si_4O_{12} + CaCO_3$.

are able to precipitate sulphides from silicates, carbonates and sulphates of the metals. Many other reactions are possible.

THE SEPARATION OF SOLID COMPOUNDS FROM WATERY SOLUTIONS.

The principal methods by which the constituents of a watery solution are separated from the solution as solids are:

I. Decreased Solvent Power by:

(*a*) *Decreased pressure or temperature*, as in the case of solutions rising from below.

(*b*) *Evaporation.* — This is practically restricted to the seas and lakes at the surface, as in the interior the hollows are soon filled with water vapor.

(*c*) *Loss of a Constituent.* — A loss of CO_2 takes place in moving water in contact with air, as at outlets of springs or rivers.

(*d*) *Solution of Another Substance.* — Solutions saturated with one substance can dissolve another, but a saturated complex solution contains less of either salt than when saturated by it alone. Hence a saturated solution coming in contact with a new substance may dissolve some of it, but if so will deposit some of the substance previously in solution.

II. Chemical Reaction or Mutual Exchange.

If a solution comes into contact with some substance, from which by chemical exchange a less soluble compound can result, a precipitation of this new substance will take place. In this way, especially in very dilute solutions or by gradual contact, many beautiful crystals are formed. Very often the reaction can be traced in pseudomorphs and altered minerals.

The law of mass action rules, that is, each material exerts chemical action proportionate to its mass. Exactly opposite results are obtainable; for instance, $BaCO_3$ with sufficient sulphate solution is all changed to $BaSO_4$ and $BaSO_4$ with sufficient carbonate solution is all changed to $BaCO_3$. If the quantity of solution is not sufficient, a stage is reached in which both salts are simultaneously in solution. Much less solution is needed to convert the comparatively easily soluble $BaCO_3$ into nearly insoluble $BaSO_4$ than for the reverse action.

THE MINERALS DEPOSITED BY SPRINGS.

The water emerging at a spring is often merely rain water which has followed a comparatively short course through the soil

and emerged at a lower elevation. It contains little more than the dissolved gases from the atmosphere. In other springs however the higher temperatures or the dissolved constituents show a deeper source. In rising, the pressure and therefore the solvent power decrease, and loss of CO_2, evaporation and reactions may all tend to the deposition of solids.

The usual constituents of spring waters are chlorides, sulphates and carbonates of the alkalis and alkaline earths, free silica, phosphates of iron or aluminum, and alkaline silicates. All of these have been obtained experimentally by treating powdered rocks with water containing CO_2.

Carbonates from Spring Waters.

Hot springs often deposit calcite or aragonite as stalactites or if the solution fall on loose sand kernels or the separation is upon some nucleus in moving water, oölitic deposits result. In brooks and rivers a compact, calc sinter forms. In iron mines aragonite separates as "flos ferri." Other carbonates, such as siderite, hydrozincite, and hydrodolomite form also. The cause is usually loss of CO_2 by diminished pressure.

Silica from Spring Water.

Massive opal is precipitated from geysers chiefly by organisms as described later. At other times quartz or chalcedony is deposited, evidently as the result of the decomposition of a silicate by carbonated water.

Sulphur and Sulphides from Springs.

Sulphur springs containing either H_2S or some sulphide are not rare. At Steamboat Springs, California, the emerging hot waters penetrate a clayey paste containing grains of cinnabar; with it are alternate beds of pyrite and chalcedony. The ascending hot waters contain alkaline carbonates and sulphides with an excess of CO_2 and H_2S, these evidently dissolved the silica of the basalt rock leaving a clay behind. By decrease of pressure the silica deposited as chalcedony and at the same time the iron and mercury must have been thrown down as sulphide. Free sulphur is also present.

Other Deposits from Springs.

Sassolite, HBO_3, scorodite, fluorite, barite, celestite, the alums, halloysite, siderite, and limonite.

THE MINERALS DEPOSITED IN VEINS.

Those clefts and cracks in the earth which penetrate to great depths and frequently occur near eruptive rocks or near springs containing CO_2 and H_2S, contain as their principal minerals quartz, barite, calcite, fluorite and the ores. Silicates are rare, crystals are frequent and the minerals are deposited on the walls of the cleft, first the most insoluble, such as quartz, then barite, calcite, fluorite and so on, usually symmetrically to the center of the cleft.

All these facts accord with the theory that these vein clefts had not a free outlet to the surface and became filled with water, which, instead of moving upward rapidly as in springs, had a hardly noticeable current and coming from below would contain CO_2 and bicarbonates and often sulphides, H_2S, and sulphates.

From the rocks cut by the vein the ground water may be assumed to have formed concentrated solutions of silicates, which reaching the vein would meet water already there and would be slowly diffused in this vein water containing CO_2, H_2S, bicarbonates, etc. The conditions would be most favorable for the formation of crystals. Reactions between CO_2 and the dissolved silicates would form quartz and carbonates and but little silicate while, by the action of H_2S and dissolved sulphides on the metallic compounds, there would result insoluble sulphides of heavy metals and the sulphates would cause barite. The most insoluble compounds would be deposited first.

MINERALS FORMED BY THE GROUND WATER IN THE ROCK MASS.

The action of the "ground" water in dissolving the minerals throughout the rock mass is accompanied by new formations whereever the necessary solid, liquid or gaseous precipitant is encountered. Solutions from some vein cleft may be diffused through the pores of the decomposing rock or may communicate with crevices and penetrate sediments and cause therein production of the same minerals. The minerals thus produced are principally calcite and quartz and more rarely gypsum or sulphides, such as cinnabar, pyrite, sphalerite or chalcopyrite. So also partially altered material and pseudomorphs may be found through the mass, and entire rock masses may be altered producing, according to their composition, clays, chlorites, serpentines, talcs, calcite, quartz, limonite, epidote and the micas.

Certain secondary minerals which can not be traced to the deep veins are evidently due to the watery solutions which have formed in the upper portion of the earth's crust.

The minerals are either those of the adjacent rock or their components are derived therefrom. Beautiful druses of brilliant crystals are found lining cavities and clefts in the rocks, and in the hollows due to gases and vapors at the time of formation. Often two or more species occur in symmetrical layers on the walls. They occur more frequently in rocks low in silica, because the soluble substances necessary to their formation are more plentiful. The more common species are quartz, chalcedony, calcite, siderite, the various zeolites, datolite, prehnite, barite, delessite, etc. Here belong also the new formed crystals in clay, marl or sand and the cementing material of conglomerates and sandstones.

THE MINERALS FORMED IN OCEANS, SEAS AND LAKES.

Rivers and brooks carry to the seas and lakes into which they empty, mineral fragments in suspension which are mechanically deposited, and substances in solution which by concentration and reactions form minerals. The principal constituents are sulphates, chlorides and carbonates of calcium, magnesium and sodium. The proportion in which they stand is very different in the rivers and the oceans.

Average of Five Great Rivers.		Ocean.
Carbonates,	80	0.2
Chlorides,	7	90
Sulphates,	13	10

The proportion of dissolved solids in the ocean is only 33 to 37 in the 1000. Deep sea dredgings bring to light principally a red clay containing minute crystals of a rare zeolite called phillipsite, nodules of hydrated oxide of manganese and iron and some enstatite, all apparently resulting from the decomposition of a lava.

For the dissolved constituents to separate there is needed a concentration of the solution, that is, a land-locked basin and a warm climate. With these conditions there separate various minerals ; in order generally of their solubility, but thus dependent also upon the proportion of associates and the temperature.

The Formation * of the Stassfurt Salt Deposit as a Type.

Five regions may be named commencing at the bottom.

1. The Anhydrite ($CaSO_4$) region, composed chiefly of rock salt, but with strings of anhydrite varying from 4 to 9 per cent. of all. Thickness 330 meters.

2. The Polyhalite ($2CaSO_4.MgSO_4.K_2SO_4.\ 2H_2O$) region, composed of halite, 91.2 ; anhydrite, 0.7 ; polyhalite, 6.2 ; tachydrite, 1.5 per cent. Thickness 62 meters.

3. The Kieserite ($MgSO_4.H_2O$) region, composed of halite, 65.0 ;

* Condensed principally from Braun's *Chemische Mineralogie*, pp. 340-346.

kieserite, 17; carnallite, 13; tachydrite, 3.0; anhydrite, 2 per cent. Thickness 56 meters.

4. The Carnallite ($KCl.MgCl_2.6H_2O$) region, composed of carnallite, 55.0; kieserite, 16.9; halite, 25.0; tachydrite, 4.0 per cent. Thickness 42 meters, but in successive thin layers in the order named. Here occur also a large number of secondary minerals.

5. The Kainite ($MgSO_4.KCl.3H_2O$), a secondary formation on the rise of the strata and due to the action of a limited quantity of water on kieserite and carnallite. Above these there is a later formation of salt clay and successive layers of anhydrite, halite and thin layers of polyhalite. Thickness, 40 to 90 meters.

The primary minerals were probably only anhydrite, halite, polyhalite, kieserite, carnallite, possibly part of sylvite and boracite, the less soluble separating first.

Theory as to Formation. — Probably a basin of the sea was separated from the ocean by a bar, gradually concentrated by evaporation but with constant addition of more sea water. There would be a separation first of gypsum and halite, then, as the magnesia contents increased, gypsum would be hindered and anhydrite formed. In time there would be at the bottom of the basin a strong solution rich in magnesia salts, while above, the constant inflow and overflow at the bar would result in a relatively dilute solution.

At a later date the raising of the bar apparently converted the basin into a salt lake which evaporation and the gradual separation of the halite converted into a supersaturated solution of magnesium sulphate from which kieserite crystallized. The mother liquor then evidently consisted of an excess of $MgCl_2$ with KCl, for only then, in experiments, will the double salt, carnallite, form.

Other reactions produced secondary minerals, as described by Braun.

MINERALS FORMED IN SODA LAKES.

In certain lakes, carbonates, borates and sulphates predominate. Near Laramie, Wyoming, are deposits 20 to 30 feet deep, principally of sodium sulphate, mirabilite, $Na_2SO_4 + 10H_2O$.

The same mineral separates from the Great Salt Lake, when the temperature is low, and is heaped up by the waves on the beaches where, if not collected, it redissolves as soon as the temperature rises.

In other lakes and pools and in a crust resulting from their

evaporation there is found the mineral trona, $Na_2CO_3.NaHCO_3.2H_2O$; and less frequently two other carbonates, natron and thermonatrite.

MINERALS FORMED IN BORAX LAKES AND LAGOONS.

Borax lakes and lagoons are found in regions of volcanic activity and have probably received boric acid from hot springs. According to their other contents there may separate sassolite, HBO_3, borax, colemanite or other borates. If sulphates are present they will also separate.

Borax Lake, Cal., for instance, furnishes anhydrite, calcite, celestite, cerargyrite, colemanite, dolomite, embolite, gaylussite, glauberite, gold, halite, natron, soda-nitre, sulphur, thenardite, trona, hanksite and sulphohalite.

MINERAL FORMATION BY ORGANISMS.

A great portion of the solid earth is due to lower forms of animal and vegetable life. Corals, mussels, echinoderms, etc., in some way take calcium * from sea water and build with it shells and frame works, chiefly of $CaCO_3$. Plant organisms, algæ, nullipores, etc., precipitate $CaCO_3$, which in this way forms reefs and banks of limestone.

The change to crystalline limestone is due chiefly to carbonated water, sometimes assisted by heat and pressure, which dissolve the amorphous material and at the same time precipitate the less soluble crystalline material. Fresh-water limestones (calc-tufa or travertine) are formed by the precipitation of $CaCO_3$ from springs, rivers and brooks rich in calcium bicarbonate, by algæ, moss and other plants which, needing CO_2 for nourishment, take it, thereby precipitating upon them the insoluble carbonate and dying, except at the top, gradually form a spongy mass of calcite or aragonite.

Dolomite, $CaCO_3.MgCO_3$, in mighty mountain ranges is formed from organically precipitated $CaCO_3$ containing much less than the requisite per cent. of $MgCO_3$. Most coral has less than one per cent., but certain lithothamniens often found on the outside of coral reefs contain up to 13 per cent. $MgCO_3$. One explanation of the enrichment is that the $CaCO_3$ of corals is aragonite, since by experi-

* The Ca must be largely obtained from $CaSO_4$ as the ocean contains only a little bicarbonate. One assumption is that plant organisms decompose the $CaSO_4$ and that they are eaten by animals. Another, that it is decomposed directly in the animal. Organisms develop $(NH_4)_2CO_3$ which would precipitate the lime as carbonate.

ment in concentrated salt solution about 42 per cent. of aragonite is changed to $MgCO_3$ by contact with $MgSO_4$ at 91° C., giving essentially dolomite. In a closed sea basin in a warm climate these conditions would prevail.

Silica is taken from ocean water by sponges, radiolaria, etc., and forms banks of hornstone. Diatoms in marshes form siliceous coatings and these yield great beds of soluble silica (diatomaceous earth). Algæ in hot springs precipitate geyserite.

Sulphur is separated from sulphates by certain algæ and bacteria, and from sulphates by decomposing organic matter.

Limonite (bog ore) is in part due to one of the algæ which builds iron into its structure, but it is most of it due to the acids resulting from the decomposition of plants which dissolve iron from the soil and the solution later decomposes into limonite, CO_2 and H_2O.

Pyrite, *marcasite* and some other sulphides are precipitated from solutions by decomposing organic matter.

Nitre forms as the result of a fermentation involving bacteria.

Chemical and physical changes take place as the result of light, some precipitations are electrolytic and the absorbing or losing of water may effect an entire change in the structure and nature of a species.

CHAPTER XXI.

THE IRON MINERALS.

THE minerals described are:

Metal	**Iron**	Fe	
Sulphides	**Pyrrhotite**	Fe_nS_{n+1}	Hexagonal
	Pyrite	FeS_2	Isometric
	Marcasite	FeS_2	Orthorhombic
Sulpharsenide	**Arsenopyrite**	FeAsS	"
Arsenide	*Leucopyrite*	Fe_3As_4	"
Oxides	**Magnetite**	Fe_3O_4	Isometric
	Franklinite	$(Fe.Mn.Zn)_3O_4$	"
	Hematite	Fe_2O_3	Hexagonal
	Ilmenite	$(Fe.Ti)_2O_3$	"
Hydroxides	*Turgite*	$Fe_4O_5(OH)_2$	
	Goethite	$FeO(OH)$	Orthorhombic
	Limonite	$Fe_2(OH)_6.Fe_2O_3$	
Sulphates	**Copiapite**	$Fe_2(FeOH)_2(SO_4)_5 + 18H_2O$	Monoclinic
	Melanterite	$FeSO_4 + 7H_2O$	"
Phosphate	*Vivianite*	$Fe_3(PO_4)_2 + 8H_2O$	"
Carbonate	**Siderite**	$FeCO_3$	Hexagonal
Chromate	**Chromite**	$FeCr_2O_4$	Isometric
Columbate	*Columbite*	$Fe(CbO_3)_2$	Orthorhombic
Tungstate	**Wolframite**	$(FeMn)WO_4$	Monoclinic

Economic Importance.

The iron minerals have important and varied uses, which may briefly be described under the following heads:

I. — In natural state.
II. — For extraction of metal (ores of iron).
III. — For extraction of acid constituents.
IV. — For extraction of included metals.

I. — Uses in Natural State.

In 1902 the production of ocher, umber and sienna and natural oxide paints was 55,320 short tons.* Limonite and hematite are the principal natural oxides ground for paint.

II. — Minerals Used as Ores of Iron.

In the United States the minerals smelted for iron are, in order

* *Mineral Industry*, 1902.

of quantity used,* hematite, limonite, magnetite, and siderite. Goethite and turgite are commercially included with limonite under the name brown hematite, and some ilmenite is smelted with other ores. The residues from the roasting of pyrites are sometimes used as a source of iron, but not in this country.

In 1903 the United States produced 31,605,550† long tons of iron ore, about three quarters of which came from the Lake Superior region of Wisconsin and Minnesota, and about one sixth came from the Southern States.

The greater portion of the iron ore mined in the world each year is converted into *pig iron*, of which 44,558,000 tons were produced in 1902. That is, the ore is deprived of its oxygen by the action of incandescent carbon and the hot reducing gases resulting from its combustion, and becomes a liquid mass of metallic iron, combined and mixed with a little carbon, silicon, phosphorus, sulphur and other impurities. The furnace used is a vertical shaft, everywhere circular in horizontal section, but usually widening from the top downwards to a certain level, and then again narrowing to the hearth. Hot air is forced into the furnace through nozzles called tuyères, entering just above the hearth.

The ore and fuel are analyzed and some flux is added, which, when combined with the ash of the fuel and the foreign ingredients of the ore, forms a definite silicate of known fusibility, called the slag. The temperature of the furnace differs at different levels, but is practically the same at all times at any one level.

The ore, charged at the top, in alternate layers with fuel and flux, passes through zones of different temperature as it descends, and is reduced, carburized, fused, and flows into the hearth. The slag forms in a definite zone after the complete reduction of the iron, and falls also to the hearth, but, being lighter, floats on the melted iron until drawn off. From time to time the metal is run out into sand moulds, forming the pigs or *pig iron*, of which 17,942,840‡ long tons were produced in the United States in 1903.

This pig iron, by various processes, is converted into wrought iron, cast iron and steel.

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*John Birkinbine, in *Mineral Resources of United States*, 1902, p. 42, gives as amounts mined for one year; Hematite, 30,532,149 tons or 85.9 per cent.; limonite and goethite, 3,305,484 tons or 9.6 per cent.; magnetite, 1,688,860 tons or 4.7 per cent.; siderite, 27,642 tons.

† *Engineering and Mining Journal*, 1904, p. 46.

‡ *Loc. cit.*

The mineral franklinite, after treatment for zinc, and certain manganiferous hematites and siderites, are smelted, for *spiegeleisen*, an alloy of iron and manganese, used as a source of carbon and manganese in the manufacture of steel.

III. — Minerals Used for Extraction of Acid Constituents.

(*a*) FOR SULPHUR. — Pyrite, and, to a less extent, marcasite and pyrrhotite, are very extensively used in the manufacture of sulphuric acid. In 1903, 580,000 tons were so used in the United States. The sulphides are burned in furnaces with grates, and the gases are converted into sulphuric acid. The residues, in addition to iron, frequently contain copper, nickel or gold, and these are usually extracted later.

(*b*) FOR ARSENIC. — The mineral arsenopyrite is the chief source of arsenic. See p. 270.

(*c*) FOR CHROMIUM. — Practically all the chromium compounds derive their chromium from the mineral chromite, very little of which is now mined in the United States. The most important compounds manufactered are: potassium bichromate, used in calico printing, oxidizing rubber, bleaching indigo and in manufacturing chrome paints and matches; potassium chromate used in the manufacture of aniline colors, etc., and ferro-chromium, which added to steel produces the tough alloy known as chrome-steel.

(*d*) FOR TUNGSTEN. — Tungsten and the tungstates are extracted from wolframite and scheelite. The world's product is not more than 600 to 700 tons, and is chiefly employed in the manufacture of crude tungsten for self-hardening tungsten steel and sodium tungstate for rendering fabrics non-inflammable.

IV. — Included Metals.

(*a*) GOLD AND SILVER. — Both pyrite and arsenopyrite frequently carry gold and a little silver, which may be extracted either directly by stamping and amalgamation or, more completely, by treatment of the roasted residues with chlorine or potassium cyanide solution.

(*b*) NICKEL. — Pyrrhotite frequently carries nickel, and in 1898 about 2,700 tons of nickel were extracted from the pyrrhotite of Sudbury, Ontario.

IRON.

COMPOSITION. — Fe with some Ni, Cr, Co, Mn.

GENERAL DESCRIPTION. — Masses and imbedded particles of white to gray metal, resembling manufactured iron. Many meteorites are alloys of nickel and iron and

usually, when polished and etched by dilute acid, exhibit lines or bands, due to a crystalline arrangement of alloys of different proportion of Fe to Ni. Figs. 309, 310.

PHYSICAL CHARACTERS. — Opaque. Lustre, metallic. Color, steel-gray to iron-black. Streak, metallic gray. H., 4 to 5. Sp. gr., 7.3 to 7.8. Tough and malleable. Fracture, hackly.

BEFORE BLOWPIPE, ETC. — Infusible. Soluble in acids. In borax or salt of phosphorus, reacts only for iron.

FIG. 309.

FIG. 310.

Sections of Iron Meteorites Etched with Acid.

REMARKS.—Occurs in large masses on Disco Island, Greenland, and sparingly in some basalts, pyrite nodules, etc., and locally reduced by heat from the carbonate. Also found in most meteorites either as chief constituent or as a spongy matrix or in disseminated grains.

PYRRHOTITE.—Magnetic Pyrites, Mundic.

COMPOSITION.—Fe_nS_{n+1}. Fe_6S_7 to $Fe_{11}S_{12}$, with frequently small percentages of cobalt or nickel.

GENERAL DESCRIPTION.—Usually a massive bronze metallic mineral, which is attracted by the magnet and can be scratched with a knife. Sometimes occurs in tabular hexagonal crystals.

Physical Characters. H., 3.5 to 4.5. Sp. gr., 4.5 to 4.6.

LUSTRE, metallic. OPAQUE.

STREAK, grayish-black. TENACITY, brittle.

COLOR, bronze-yellow to bronze-red, but subject to tarnish.

Attracted by the magnet.

BEFORE BLOWPIPE, ETC.—Fuses readily on charcoal to a black magnetic mass, evolves fumes of sulphur dioxide, but does not take fire. In closed tube, yields a little sulphur. In open tube, gives fumes of sulphur dioxide. Soluble in hydrochloric acid, with evolution of hydrogen sulphide and residue of sulphur.

SIMILAR SPECIES.—Pyrrhotite resembles pyrite, bornite and niccolite at times, but differs in being attracted by the magnet and by its bronze color on fresh fracture.

REMARKS.—Pyrrhotite is found in gabbros and schists and occasionally in the older eruptive rocks, also frequently in meteorites. It alters to pyrite, limonite and siderite.

Immense quantities are found at Strafford and Ely, Vermont; Sudbury, Canada, and Lancaster Gap, Pennsylvania. The last two deposits are nickeliferous, and are mined for this metal. Smaller beds are common.

USES.—It is one of the chief ores of nickel, probably from included minerals; and to some extent is an ore of sulphur.

PYRITE.—Iron Pyrites, Fool's Gold.

COMPOSITION.—FeS_2 (Fe 46.7, S 53.3 per cent.), often containing small amounts of Cu, As, Ni, Co, Au.

GENERAL DESCRIPTION.—A brass-colored, metallic mineral, frequently in cubic or other isometric crystals or in crystalline masses, which may be any shape, as botryoidal, globular, stalactitic, etc. Less frequently in non-crystalline masses.

FIG. 311.

Pyrite in Schist, Lourdes. After Lacroix.

CRYSTALLIZATION. — Isometric, class of diploid, p. 59. Most common forms are cube *a*, Fig. 312, and pyritohedron *e*, Fig. 313, $a : 2a : \infty a$; $\{210\}$ or combinations of these, Fig. 315. The octahedron also occurs alone, Fig. 314, or in combination with *a* and

e, Figs. 316, 317, 318, and the diploid $s = (a : \frac{3}{2}\,a : 3a)$; $\{321\}$ is not rare in combinations, Fig. 319, 320.

The faces of the cube and pyritohedron are frequently striated in one direction parallel to intersections of these two forms. See Fig. 251.

FIG. 312.

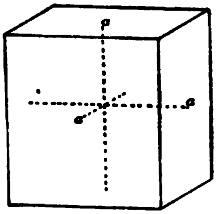


FIG. 313.

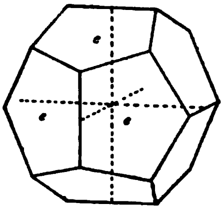


FIG. 314.

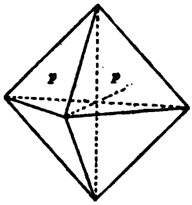


FIG. 315.

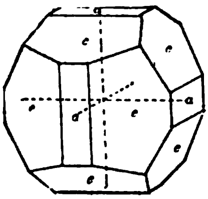


FIG. 316.

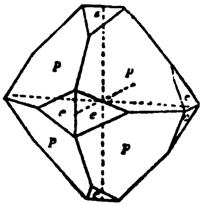


FIG. 317.

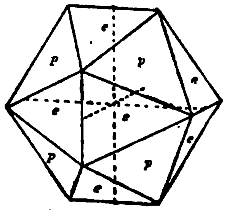


FIG. 318.

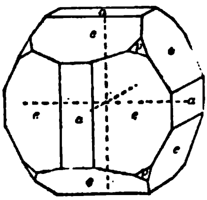


FIG. 319.

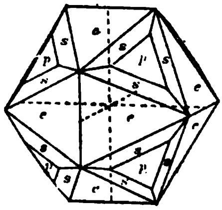
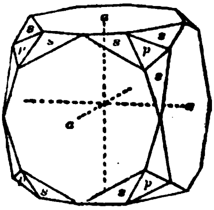


FIG. 320.



Physical Characters. H., 6 to 6.5. Sp. gr., 4.9 to 5.2.

LUSTER, metallic. OPAQUE.
STREAK, greenish-black. TENACITY, brittle.
COLOR, pale to full brass-yellow and brown from tarnish.
CLEAVAGE, imperfect cubic.

BEFORE BLOWPIPE, ETC.—On charcoal, takes fire and burns with a blue flame, giving off fumes of sulphur dioxide, and leaving a magnetic residue which, like pyrrhotite, dissolves in hydrochloric acid with evolution of hydrogen sulphide. In closed tube, gives a

sulphur deposit. Insoluble in hydrochloric acid, but soluble in nitric acid with separation of sulphur.

SIMILAR SPECIES.—Pyrite is harder than chalcopyrite, pyrrhotite, or gold. It differs from gold, also, in color, streak, and brittleness.

REMARKS.—Pyrite is being formed to-day by the action of the hydrogen sulphide of thermal springs upon soluble iron salts. It has been developed in many rocks by the action of hot water on iron salts in the presence of decomposing organic matter. It may be, also, of igneous origin. Pyrite is found in rocks of all ages, associated with other metallic sulphides and with oxides of iron. In compact specimens it is not easily altered, but granular masses readily oxidize and are decomposed, forming sulphate of iron and sulphuric acid, thus acting as a vigorous agent in the decomposition of rocks. The final results are usually limonite and sulphates of calcium, sodium, magnesium, etc. Few minerals are of such general or wide spread occurrence. The most celebrated locality is the Rio Tinto region, in Spain, from which immense quantities of a gold- and copper-bearing pyrite are annually procured. The largest deposits worked in the United States are at Rowe, Mass.; Hermon, N. Y.; and at several localities in Virginia. Innumerable large deposits are known.

USES.—Pyrite is burned, for the manufacture of sulphuric acid, in enormous quantities. Pyrite containing copper or gold is sometimes treated for these metals, but, the treatment is frequently preceded by a burning for sulphuric acid. The use of pyrite for the manufacture of copperas has been superseded by a process of galvanizing iron in which copperas is a by-product.

MARCASITE—White Iron Pyrites.

COMPOSITION.—FeS_2, as in pyrite.

GENERAL DESCRIPTION.—Ferric sulphide is dimorphous. Marcasite differs from pyrite in crystalline form, and in little else. It occurs in orthorhombic forms, and in crystalline masses. The compound crystals have given rise to such names as cockscomb

FIG. 321.

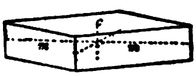
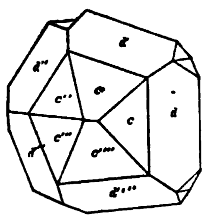


FIG. 322.

FIG. 323.



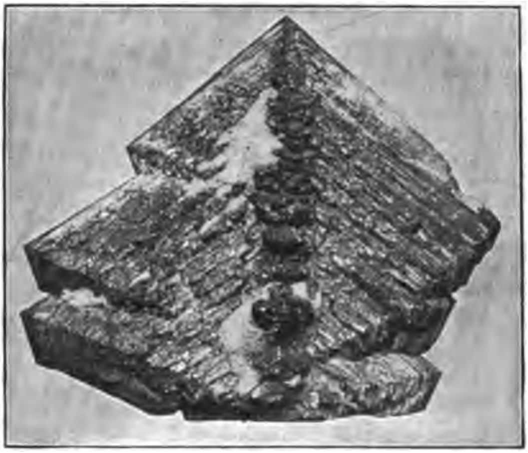
pyrites, spear pyrites, etc., from their resemblance to these objects. Often, with radiated structure. Color on fresh fracture is usually whiter than in pyrite.

CRYSTALLIZATION.— Orthorhombic, $\breve{a}:\bar{b}:\dot{c} = 0.7662:1:1.2342$. Crystals usually tabular parallel to base.

Simple forms show unit prism *m*, basal pinacoid *c* and often one or more brachy domes as $g = (\infty\breve{a}:\bar{b}:\frac{1}{3}\dot{c})$; {013}. Compound "fivelings" with twin plane *m*, Figs. 323 and 324, are frequent.

Supplement angles are $mm = 74° 55'$, $cg = 22° 21'$.

FIG. 324.



Marcasite Twin Crystal. After Lacroix.

Physical Characters. H., 6 to 6.5. Sp. gr., 4.6 to 4.9.

LUSTRE, metallic. OPAQUE.

STREAK, nearly black. TENACITY, brittle.

COLOR, pale brass-yellow, darker after exposure.

CLEAVAGE, imperfect prismatic (angle of 105° 5').

BEFORE BLOWPIPE, ETC.—As for pyrite.

SIMILAR SPECIES.—As for pyrite, from which it is only distinguishable by crystalline form, cleavage, and, to a slight degree, by lighter color.

REMARKS.—Marcasite is more readily decomposed than pyrite, and is, therefore, an even less desirable constituent in building material, etc. It is found at Cummington, Mass.; Warwick, N. Y.; Joplin, Mo.; Haverhill, N. H.; and in many other localities and is usually mistaken for pyrite.

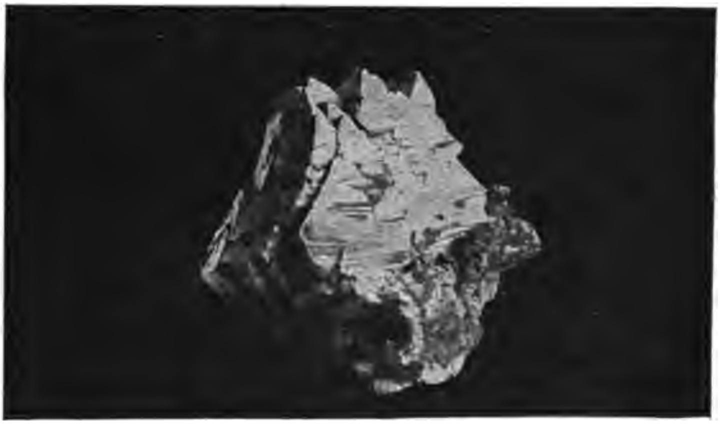
USES, are the same as for pyrite.

ARSENOPYRITE.—Mispickel.

COMPOSITION.—FeAsS. (Fe 34.4, As 46.0, S 19.6 per cent.) sometimes with replacement of iron by cobalt, or arsenic by antimony in part.

GENERAL DESCRIPTION.—Silver white to gray mineral with metallic lustre. Usually compact or in granular masses or disseminated grains. Less frequently in orthorhombic crystals or columnar.

FIG. 325.



Arsenopyrite, Freiberg, Saxony. N. Y. State Museum.

CRYSTALLIZATION. — Orthorhombic $\breve{a} : \bar{b} : \dot{c} = 0.677 : 1 : 1.188$. Common forms, unit prism m combined with a brachy dome

FIG. 326.

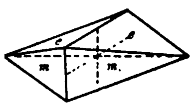


FIG. 327.

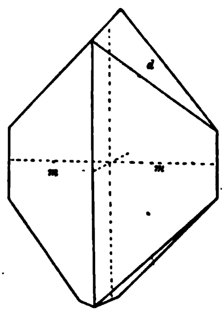
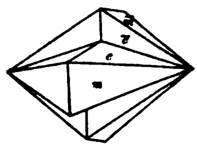


FIG. 328.



either $d = (\infty \breve{a} : \bar{b} : c)$; $\{011\}$ or $e = (\infty \breve{a} : b : \frac{1}{4}c)$; $\{014\}$. Crossed twins, Fig. 328, occur and fivelings, as in Fig. 323 of marcasite.

Supplement angles $mm = 68° \ 13'$, $dd = 99° \ 50'$, $ee = 33° \ 05'$.

Physical Characters. H. 5.5 to 6. Sp. Gr., 6 to 6.2.

LUSTRE, metallic. OPAQUE.
STREAK, grayish-black. TENACITY, brittle.
COLOR, silver white to steel gray.
CLEAVAGE, prismatic (111° 47).

BEFORE BLOWPIPE, ETC.—In closed tube yields a red sublimate, yellow when cold. On charcoal yields abundant white fumes and arsenical odor and coating and fuses to a magnetic globule. After short treatment the residue is soluble in hydrochloric acid with evolution of hydrogen sulphide and precipitation of the yellow sulphide of arsenic. The residue may react for cobalt. Insoluble in hydrochloric acid. Soluble in nitric acid with separation of sulphur.

SIMILAR SPECIES.—Massive varieties of the metallic cobalt minerals and varieties of leucopyrite resemble arsenopyrite and are only safely distinguished by blowpipe tests. Smaltite when massive can be distinguished from cobaltiferous arsenopyrite only by its slight reaction with hydrochloric acid after fusion.

REMARKS.—Arsenopyrite is found chiefly in crystalline rocks with other metallic sulphides and arsenides. Throughout the Rocky Mountains it is a common mineral and frequently auriferous. A large deposit at Deloro, Canada, is mined for both arsenic and gold. The arsenopyrite found in New England usually contains cobalt.

USES.—Arsenopyrite is the source of most of the arsenic of commerce, and occasionally contains enough gold or cobalt to pay for extraction.

LEUCOPYRITE.—Löllingite.

COMPOSITION.—Fe_3As_4 to $FeAs_2$ sometimes with Co, Ni, Au or S.

GENERAL DESCRIPTION.—Massive silver-white or gray metallic mineral sometimes occurring in orthorhombic crystals, closely agreeing in angles with crystals of arsenopyrite.

PHYSICAL CHARACTERS.—Opaque. Lustre, metallic. Color, silver-white or gray. Streak, grayish-black. H. = 5 to 5.5. Sp. gr., 7 to 7.4. Brittle. Cleavage, basal.

BEFORE BLOWPIPE, ETC.—Like arsenopyrite, except that sulphur reactions are less pronounced or do not appear at all.

MAGNETITE.—Lodestone, Magnetic Iron Ore.

COMPOSITION.—Fe_3O_4 (Fe, 72.4 per cent.) often contains Ti, Mg.

GENERAL DESCRIPTION.—A black mineral with black streak and metallic lustre, *strongly* attracted by the magnet and occurring in all conditions from loose sand to compact coarse or fine grained masses.

CRYSTALLIZATION. — Isometric, usually octahedra, Fig. 329, or loosely coherent masses of imperfect crystals, see Fig. 268. Sometimes the dodecahedron *d*, Fig. 330, or a combination of these,

FIG. 329.

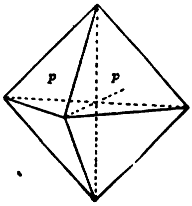


FIG. 330.

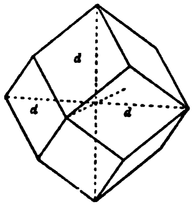


FIG. 331.

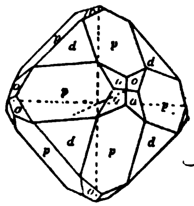


Fig. 333, or more rarely with the angles modified by the trapezohedron $o = (a : 3a : 3a)$; $\{311\}$. Fig. 331.

Twinning parallel to an octahedral face occurs, sometimes shown by striations upon the octahedral faces, as in Fig. 250.

FIG. 332.

Magnetite in Schist, *Geikie*.

Physical Characters. H., 5.5 to 6.5. Sp. gr., 4.9 to 5.2.

LUSTRE, metallic to submetallic. OPAQUE.

COLOR and STREAK, black. TENACITY, brittle.

Strongly attracted by magnet and sometimes itself a magnet (lodestone). Breaks parallel to octahedron.

BEFORE BLOWPIPE, ETC.—Fusible with difficulty in the reducing flame. Soluble in powder in hydrochloric but not in nitric acid.

SIMILAR SPECIES.—No other black mineral is strongly attracted by the magnet.

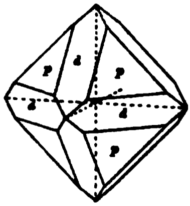
REMARKS.—Magnetite occurs chiefly in crystalline metamorphic rocks and in eruptive rocks partly derived from silicates containing iron. It is little altered by exposure but organic matter reduces it to ferrous oxide which by oxidation becomes hematite, Fe_2O_3.

It makes up about 12 per cent. of the iron ore mined in America, being obtained especially from the States of Pennsylvania, New York, New Jersey and Michigan. Smaller amounts are obtained elsewhere and it is present in many localities. In this country, lodestones are obtained mainly from Magnet Cove, Ark. Whole mountains are made up of this mineral in Sweden and it is practically the only iron-ore mined in that country.

USES.—It is an important iron ore highly valued for its purity.

FRANKLINITE.

FIG. 333.



COMPOSITION.—(Fe.Mn.Zn) $(Fe.Mn)_2O_4$.

GENERAL DESCRIPTION.—A black mineral resembling magnetite. Occurs in compact masses, rounded grains and octahedral crystals. Only slightly magnetic and generally with brown streak. The red zincite and yellow to green willemite are frequent associates. The crystals are modified octahedrons rarely sharp cut as in magnetite.

Physical Characters.—H., 6 to 6.5. Sp. Gr., 5 to 5.2.

LUSTRE, metallic or dull.	OPAQUE.
STREAK, brown to black.	TENACITY, brittle.
COLOR, black.	Breaks parallel to octahedron.
Slightly magnetic at times.	

BEFORE BLOWPIPE, ETC.—Infusible. On charcoal with soda gives white coat of zinc oxide. In beads gives manganese reaction. Slowly soluble in hydrochloric acid with evolution of some chlorine.

SIMILAR SPECIES.—Distinguished from magnetite and chromite by bead tests and associates.

REMARKS.—The only noteworthy locality is that in the vicinity of Franklin Furnace, New Jersey. Here, however, the deposit is large and has been extensively developed.

USES.—The zinc is recovered as zinc white and the residue is smelted for spiegeleisen an alloy of iron and manganese used in steel manufacture. Franklinite has also been ground for a dark paint.

HEMATITE.—Specular Iron, Red Iron Ore.

COMPOSITION.—Fe_2O_3, (Fe 70 per cent.), often with SiO_2, MgO, etc., as impurities.

GENERAL DESCRIPTION.—Occurs in masses varying from brilliant black metallic to blackish red and brick red with little lustre.

The black is frequently crystallized, usually in thin tabular crystals set on edge in parallel position, less frequently in larger highly modified forms and finally in scale-like to micaceous masses. The red varieties vary from compact columnar, radiated and kidney-shaped masses to loose earthy red material. In *all* varieties the streak is *red.*

CRYSTALLIZATION. — Hexagonal, scalenohedral class, p. 42. Axis $\dot{c} = 1.365$.

The most common forms on the Elba crystals are the unit rhombohedron p and the scalenohedron $n = (2a : 2a : a : \frac{4}{3}c)$; $\{22\bar{4}3\}$. The rhombohedron $g = (a : \infty a : a : \frac{1}{4}c$; $\{10\bar{1}4\}$ also

FIG. 334.

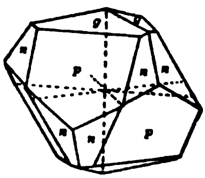


FIG. 335.

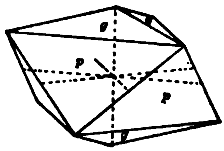
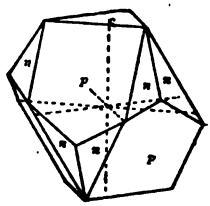


FIG. 336.



occurs. Thin plate-like crystals are the rule at other localities. Sometimes grouped in rosettes, as in the "Eisenrosen," Fig. 337.

Supplement angles. — $pp = 94°$; $nn = 51° 59'$; $cp = 57° 37'$; $gg = 37° 2'$; $cn = 61° 13'$.

FIG. 337.

Eisenrosen, Fibia Switz.

FIG. 338.

Radiated reniform, *Geikie.*

Physical Characters. H., 5.5 to 6.5. Sp. gr., 4.9 to 5.3.

LUSTRE, metallic to dull.

STREAK, brownish red to cherry red.

COLOR, iron black, blackish red to cherry red. Sometimes slightly magnetic.

OPAQUE.

TENACITY, brittle unless micaceous.

BEFORE BLOWPIPE, ETC.—Infusible. Becomes magnetic in reducing flame. Soluble in hot hydrochloric acid. In borax reacts for iron.

VARIETIES.

Specular Iron.—Brilliant micaceous or in crystals. Black in color.

Red Hematite.—Submetallic to dull, massive, blackish red to brownish red in color.

Red Ochre.—Earthy impure hematite usually with clay. Often pulverulent.

Clay Ironstone.—Hard compact red material mixed with much clay or sand.

Martite.—Octahedral crystals, probably pseudomorphs.

SIMILAR SPECIES.—Resembles at times the other iron-ores and massive cuprite. It is distinguished by its streak and strong magnetism after heating in reducing flame.

REMARKS.—Usually in metamorphic rocks, probably formed from bog iron-ore by pressure and heat. Also found in igneous rocks. Changes by action of atmosphere, water, organic matter, etc., into limonite, siderite and magnetite. About 72 per cent. of the iron-ore mined in the United States is hematite. By far the larger part is obtained from the Marquette and Gogebic ranges of Michigan and from the Mesabi range in Minnesota. Smaller but by no means inconsiderable amounts are mined in New York, Alabama, Missouri and other states.

USES.—In this country it supplies seven eighths of all the iron ore mined. The earthy varieties are used for a cheap paint, and some massive varieties are ground for paint or polishing material.

ILMENITE.—Menaccanite, Titanic Iron-Ore.

COMPOSITION.—$(Fe.Ti)_2O_3$, sometimes containing small amounts of Mg or Mn.

FIG. 339.

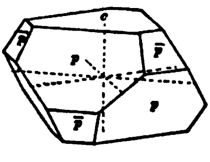
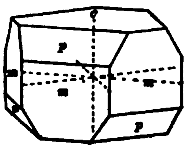


FIG. 340.



GENERAL DESCRIPTION.—An iron-black mineral, usually massive or in thin plates or imbedded grains or as sand. Also, in crystals closely like those of hematite in angle.

CRYSTALLIZATION.—Hexagonal. Class of third order rhom-

bohedron, p. 48. Axis $c = 1.385$. Usually thick plates showing basal pinacoid c, unit prism m and unit rhombohedron p, Fig. 340, or without the prism, Fig. 339. Supplement angles $pp = 94° 29'$; $cp = 57° 58'$.

Physical Characters.—H., 5 to 6. Sp. gr., 4.5 to 5.

LUSTRE, submetallic.	OPAQUE.
STREAK, black to brownish-red.	TENACITY, brittle.
COLOR, iron-black,	Slightly magnetic.

BEFORE BLOWPIPE, ETC.—Infusible in oxidizing flame; slightly fusible in reducing flame. In salt of phosphorus gives a red bead which, on treatment in reducing flame becomes violet, slowly soluble in hydrochloric acid and the solution boiled with tin is violet and on evaporation becomes rose-red.

SIMILAR SPECIES.—Differs from magnetite and hematite in the titanium reactions.

REMARKS.—Menaccanite occurs in crystalline rocks, often with magnetite. It is sometimes altered to limonite and to titanite.

Immense beds occur at Bay St. Paul, Quebec, and other points in Canada. Found also in the county of Orange, N. Y., in Massachusetts, Connecticut, and elsewhere. A Norwegian locality Kragëro, is, for its large crystals, perhaps the most celebrated.

USES.—It is used as a constituent of the lining of puddling furnaces.

GOETHITE.

COMPOSITION.—FeO(OH). Fe, 62.9 per cent.

GENERAL DESCRIPTION.—A yellow, red or brown mineral, occurring in small, distinct, prismatic crystals (orthorhombic), often flattened like scales, or needle-like, or grouped in parallel position. These shade into feather-like and velvety crusts. Occurs also massive like yellow ochre.

PHYSICAL CHARACTERS.—Opaque to translucent. Lustre, adamantine to dull. Color, yellow, reddish, dark-brown and nearly black. Streak, yellow or brownish-yellow. H., 5 to 5.5. Sp. gr., 4 to 4.4.

BEFORE BLOWPIPE, ETC.—Fuses in thin splinters to a black magnetic slag. In closed tube yields water. Frequently reacts for manganese. Soluble in hydrochloric acid.

USES.—Goethite is an ore of iron, but is commercially classed with limonite under the name of brown hematite. Large deposits are reported in Minnesota.

TURGITE. — Hydrohematite.

COMPOSITION. — $Fe_4O_5(OH)_2$, Fe = 66.2 per cent.

GENERAL DESCRIPTION. — Nearly black, botryoidal masses and crusts resembling limonite but with a red streak and often with a fibrous and satin-like appearance on fracture. Also bright red earthy masses. Usually associated with limonite or hematite.

PHYSICAL CHARACTERS. — Opaque. Lustre, submetallic to dull. Color, dark reddish-black in compact form, to bright red in ocherous variety. Streak, brownish red. H., 5.5-6. Sp. Gr., 4.29-4.68.

BEFORE BLOWPIPE, ETC. — Decrepitates violently, turns black and becomes magnetic. Yields water in closed tube with *violent decrepitation.*

SIMILAR SPECIES. — Is distinguished from limonite and hematite by its violent decrepitation when heated, its red streak, and its water test.

REMARKS. — Like goethite it is frequently mistaken for and classed with limonite. It occurs with limonite at Salisbury, Conn., and in various localities in Prussia and Siberia.

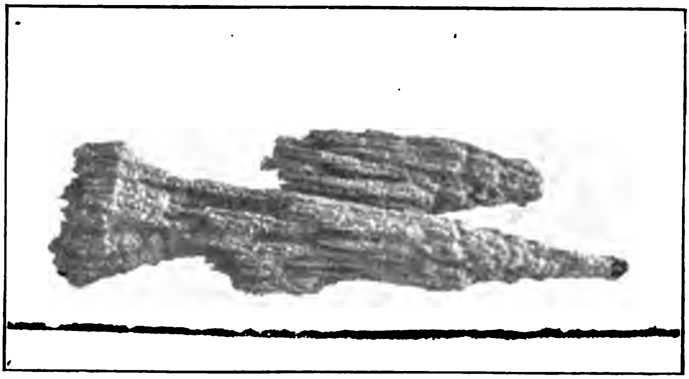
USES. — It is an ore of iron but commercially is classed with limonite.

LIMONITE. — Bog-Ore, Brown Hematite.

COMPOSITION. — $Fe_2(OH)_6Fe_2O_3$, (Fe, 59.8 per cent.). Frequently quite impure, from sand, clay, manganese, phosphorus, etc.

GENERAL DESCRIPTION. — Never crystallized, but grading from

FIG. 341.



Stalactite of Limonite, Hungary. Columbia University.

the loose, porous bog-ore and earthy ochre of brown to yellow color and dull lustre; to compact varieties, often with smooth, black, varnish-like surface, but on fracture frequently showing a somewhat silky lustre and a fibrous radiated structure. Sometimes stalactitic, Fig. 341, and often with smooth rounded surfaces and in pseudomorphs.

Limonite is recognized principally by its yellowish-brown streak and absence of crystallization. It is frequently found pseudomorphous, the original iron-bearing mineral having "changed" to limonite.

Physical Characters. H., 5 to 5.5. Sp. gr., 3.6 to 4.

LUSTRE, varnish-like, silky, dull. OPAQUE.

STREAK, yellowish-brown, TENACITY, brittle, earthy.

COLOR, brown, nearly black, yellow like iron rust.

BEFORE BLOWPIPE, ETC.—In closed tube yields water, and becomes red. Fuses in thin splinters to a dark magnetic slag. Usually reacts for silica and manganese. Soluble in hydrochloric acid, and may leave a gelatinous residue.

VARIETIES.

Bog-Iron, loosely aggregated ore from marshy ground, often intermixed with and replacing leaves, twigs, etc.

Yellow ochre, *umber*, etc., earthy material, intermixed with clay.

Brown clay ironstone, compact, often nodular masses, impure from clay.

SIMILAR SPECIES.—Distinguished from other iron-ores, except goethite, by its streak, and from the latter by lack of crystallization.

REMARKS.—One usual result of the decomposition of any iron-bearing mineral is limonite. The decomposition by water, carbon dioxide and organic acids, produces soluble iron salts, which are carried to some valley by the streams, and by oxidation the relatively insoluble limonite forms as a scum on the water and then sinks to the bottom as bog-ore. In time, by pressure, heat, etc., these deposits are compacted.

Limonite constitutes about 15 per cent. of the iron-ore mined in the United States. The largest deposits which are regularly mined exist in the States of Virginia, Alabama, Pennsylvania, Michigan, Tennessee, and Georgia.

USES.—It is the most abundant ore of iron, but is relatively impure and low in iron. The earthy varieties are used as cheap paints, and after burning are darker in color, and are called burnt umber, burnt sienna, etc.

COPIAPITE.—Misy.

COMPOSITION.—$Fe_2(FeOH)_2(SO_4)_5 + 18H_2O$, ($Fe_2O_3$ 30.6, SO_3 38.3, H_2O 31.1 per cent.) often with some Al_2O_3 or MgO.

GENERAL DESCRIPTION.—Brownish-yellow to sulphur-yellow mineral, occurring granular massive, or in loosely compacted crystalline scales, rarely, as tabular monoclinic crystals. It has a disagreeable metallic taste.

Physical Characters. H., 2.5. Sp. gr., 2.1.

LUSTRE, pearly, feeble, TRANSLUCENT.

STREAK, yellowish-white, TASTE, metallic, nauseous.

COLOR, brownish-yellow to sulphur-yellow.

BEFORE BLOWPIPE, ETC.—On charcoal, fuses and becomes magnetic. Yields much water in closed tube, and some sulphuric acid. Soluble in water. Decomposed by boiling water. With soda gives sulphur reaction.

REMARKS.—Copiapite results from the oxidation of pyrite, marcasite and pyrrhotite. It occurs with these minerals and with other sulphates.

Melanterite, $FeSO_4 + 7H_2O$. A pale green, fibrous efflorescence on pyrite or marcasite, or stalactitic massive or pulverulent. On exposure it becomes dull yellowish white. Translucent. Luster, vitreous or dull. Color, vitriol green to white. Streak, white. H., 2. Sp. gr., 1.8 to 1.9. Taste, astringent, sweetish.

VIVIANITE.—Blue Iron Earth.

COMPOSITION.—$Fe_3(PO_4)_2 + 8H_2O$. (FeO 43.0, P_2O_5 28.3, H_2O 28.7 per cent.).

GENERAL DESCRIPTION.—Usually found as a blue to bluish green earthy mineral, often replacing organic material as in bones, shells, horn, tree roots, etc. Also found as glassy crystals (monoclinic), colorless before exposure, but gradually becoming blue.

PHYSICAL CHARACTERS —Transparent to opaque. Lustre, vitreous to dull. Color and streak, colorless before exposure, but usually blue to greenish. $H = 1.5$ to 2. Sp. gr., $= 2.58$ to 2.69. Brittle.

BEFORE BLOWPIPE, ETC.—Fuses easily to a black magnetic mass and colors flame pale bluish-green, especially after moistening with concentrated sulphuric acid. In closed tube yields water. Soluble in hydrochloric acid. The dried powder is brown.

SIDERITE. — Spathic Ore.

COMPOSITION. — $FeCO_3$, (FeO 62.1, CO_2 37.9 per cent) usually with some Ca, Mg or Mn.

GENERAL DESCRIPTION. — Occurs in granular masses of a gray or brown color and also in masses with rhombohedral cleavage and in curved rhombohedral crystals, Fig. 342. At times it is quite black from included carbonaceous matter.

FIG. 342.

CRYSTALLIZATION.—Hexagonal. Scalenohedral class, p. 42. Axis $c = 0.8184$. Usually rhombohedrons of 73°, often with curved (composite) faces like those of dolomite. Optically,— with strong double refraction.

Physical Characters. H., 3.5 to 4. Sp. gr., 3.83 to 3.88.

LUSTRE, vitreous to pearly. OPAQUE to translucent.

STREAK, white or pale yellow. TENACITY, brittle.

COLOR, gray, yellow, brown or black.

CLEAVAGE, rhombohedral $R \wedge R = 107°$.

BEFORE BLOWPIPE, ETC.—Decrepitates, become black and magnetic and fuses with difficulty. Soluble in warm acids with effervescence. Slowly soluble in cold acids. May react for manganese.

SIMILAR SPECIES.—It is heavier than dolomite and becomes magnetic on heating. Some stony varieties resemble varieties of sphalerite.

REMARKS.—Siderite occurs as beds in gneiss, mica and clay-slate, etc., and as stony impure material in the coal formation. Frequently with metallic ores. It is probably chiefly formed by the action of decaying vegetation on limonite. An impure siderite forms the chief ore in Cornwall and other English mines. It is found at Catskill, N. Y., and in the coal regions of Pennsylvania, Ohio, Virginia, and Tennessee, in varying quantities, but forms only a little over one per cent. of American iron ore.

USES.—It is used as an ore of iron and when high in manganese it is used for the manufacture of spiegeleisen.

CHROMITE.—Chromic Iron.

COMPOSITION.—$FeCr_2O_4$, (FeO 32, Cr_2O_3 68 per cent.), sometimes with Al_2O_3 or MgO as replacing elements.

GENERAL DESCRIPTION.—Usually a massive black mineral resembling magnetite. Occurs either granular or compact or as disseminated grains. Rarely in small octahedral crystals. Frequently with more or less serpentine, mechanically intermixed, giving rise to green and yellow spots and streaks.

Physical Characters. H., 5.5. Sp. gr., 4.3 to 4.6.

LUSTRE, sub-metallic to metallic.	OPAQUE.
STREAK, dark-brown.	TENACITY, brittle.
COLOR, black.	May be slightly magnetic.

BEFORE BLOWPIPE, ETC.—Infusible, sometimes slightly fused by reducing flame, and *then* becomes magnetic. In salt of phosphorus, in oxidizing flame, gives yellow color hot, but on cooling becomes a fine emerald-green. With soda and nitre on platinum fuses to a mass, which is chrome-yellow when cold. Insoluble in acids.

SIMILAR SPECIES.—Chromite is distinguished from other black minerals by the salt of phosphorus reactions, and to a considerable extent by the serpentine with which it occurs.

REMARKS.—Chromite occurs in veins and masses in serpentine and has been found in large isolated pockets in Southern Pennsylvania and around Baltimore, Md., but

the richest ore has been exhausted, and most of the ore now used is brought from Turkey and from New Caledonia. Extensive deposits are also found in Del Norte, San Luis Obispo, Shasta and Placer Counties, California, but of somewhat lower grade.

USES. — Chromite is the source of the various chromium compounds, such as potassium bichromate, used in calico printing electric batteries, etc., the chrome colors and pigments. It is also used in the manufacture of a hard chrome steel and chrome bricks of a highly refractory nature.

COLUMBITE.—Tantalite.

COMPOSITION.—$Fe(CbO_3)_2$, (FeO 17.3, Cb_2O_5 82.7), but grading into tantalite. $Fe(TaO_3)_2$ without change of crystalline form. Mn is often present.

GENERAL DESCRIPTION.—Black, often iridescent prismatic crystals, in veins of granite. More rarely massive.

PHYSICAL CHARACTERS.—Opaque. Lustre, bright sub-metallic. Color, black. Streak, dark-red to black. H., 6. Sp. Gr., 5.4 to 6.5. Brittle. Cleavage in two directions at right angles.

BEFORE BLOWPIPE, ETC.—Infusible. Fused with potassium hydroxide and boiled with tin gives deep-blue solution. Insoluble in acids.

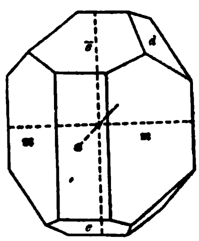
USES. — It is the chief source of columbium and tantalium salts.

WOLFRAMITE.

COMPOSITION. — $(Fe.Mn)WO_4$. (About 76.5 per cent. WO_3.)

GENERAL DESCRIPTION. — Heavy dark-gray to black submetallic crystals, orthorhombic in appearance, and also in granular or columnar masses.

FIG. 343.



Zinnwald.

CRYSTALLIZATION.—Monoclinic. Axes $\grave{a} : \bar{b} : \grave{c} = 0.830 : 1 : 0.868$, $\beta = 89° 22'$.

Usual combination shown in Fig. 343 of unit prism m, ortho pinacoid a, unit clinodome d and + and — ortho domes $e = (\grave{a} : \infty\bar{b} : \frac{1}{2}c)$; {102} angles, $mm = 79° 23'$; $dd = 81° 54'$; $a\grave{e} = 61° 54'$; $ae = 62° 54'$.

Physical Characters. — H., 5 to 5.5. Sp. gr., 7.1 to 7.55.

LUSTRE, sub-metallic.
STREAK, dark-brown to black.
COLOR, dark-gray to black.
OPAQUE.
TENACITY, brittle.
Slightly magnetic.

BEFORE BLOWPIPE, ETC. — Fuses readily to a crystalline globule, which is magnetic. In salt of phosphorus yields a reddish-yellow glass, which in reducing flame becomes green, and if this bead is pulverized and dissolved with tin, in dilute hydrochloric acid, a blue solution results.

Partially soluble in hydrochloric acid, the solution becoming blue on addition of tin.

SIMILAR SPECIES.—Distinguished by its fusibility and specific gravity from similar iron and manganese minerals.

REMARKS.—Wolframite occurs in tin veins and deposits and with other metallic minerals. It occurs altered to Scheelite and also pseudomorphous after scheelite. It is common in the Cornwall and Zinnwald tin mines. It is also found at Flowe Mountain, N. C., Monroe and Trumbull, Ct., Black Hills, Dakota, Mine la Motte, Mo., and elsewhere.

USES. — It is used to make an alloy of tungsten with steel, especially valued for permanent magnets and cutting tools, and as a source of tungsten salts, especially tungstic acid and sodium tungstate, which are used in dyeing, and as material to render cotton less inflammable.

CHAPTER XXII.

THE MANGANESE MINERALS.

THE minerals described are: *

Sulphide	*Alabandite*	MnS	
Oxides	**Braunite**	Mn_2O_3	Tetragonal
	Hausmannite	Mn_3O_4	"
	Pyrolusite	MnO_2	Orthorhombic
	Psilomelane	$MnO_2 + (H_2O.K_2O.BaO)$	
	Wad	Mixture of oxides	
Hydroxide	**Manganite**	MnO(OH)	Orthorhombic
Carbonate	**Rhodochrosite**	$MnCO_3$	Hexagonal

The principal economic use of manganese minerals is in the production of the alloys with iron, *speigeleisen* and *ferromanganese*, used in the manufacture of steel. About nine-tenths of all the manganese ore mined is used for this purpose. The method of smelting is very like that used in the manufacture of pig-iron. Manganese is also an important constituent of other alloys, especially manganese bronze and so-called silver bronze.

Minor uses are in the manufacture of chlorine, bromine, oxygen, disinfectants, driers for varnishes; as a decolorizer to remove the iron green color from glass and also, when added in larger quantity, to give an amethystine color to glass and pottery; in the ordinary dry battery; in calico printing, making green and violet paints, etc.

Certain iron ores are very rich in manganese and are valuable in making spiegeleisen. In 1902,* 901,214 long tons of manganiferous iron ores were mined in the United States. Also a large amount of franklinite was used for the production of zinc oxide and 65,246 tons * of a highly manganiferous by-product obtained.

In the West, especially in Colorado and Arizona, manganese ores often carry silver, and several thousand tons are smelted each year with other silver-bearing minerals, the manganese acting as a flux. In 1902, 194,132 tons were thus used.

The manganese minerals important as ores are the oxides

* The common silicate, rhodonite, which has no economic importance, is described under the silicates.

pyrolusite, psilomelane (including wad), braunite and manganite. In 1902 * 16,477 tons were produced mainly in Montana, Virginia and Georgia, while 235,576 tons were imported.

ALABANDITE.—Manganblende.

COMPOSITION.—MnS, (Mn 63.1, S 36.9 per cent.).

GENERAL DESCRIPTION.—A dark iron-black metallic mineral with an olive green streak. Usually massive, with easy cubic cleavage and occasionally in cubic or other isometric crystals. Also massive granular.

PHYSICAL CHARACTERS.—Opaque. Lustre, metallic. Color, deep black with brown tarnish. Streak, olive green. H., 3.5 to 4. Sp. gr., 3.95 to 4.04. Brittle.

BEFORE BLOWPIPE, ETC.—Turns brown, evolves sulphur dioxide and fuses. Gives sulphur reactions with soda. Soluble in dilute hydrochloric acid with rapid evolution of hydrogen sulphide.

SIMILAR SPECIES.—It is distinguished from all similar species by its streak.

REMARKS.—The other manganese minerals are derived in part from the alteration of this species. It occurs with other metallic sulphides.

BRAUNITE.

COMPOSITION.—Mn_2O_3, but usually containing $MnSiO_3$.

GENERAL DESCRIPTION.—Brownish black granular masses and occasional minute tetragonal pyramids almost isometric, $\dot{c} = 0.985$.

Physical Characters. H., 6 to 6.5. Sp. gr., 4.75 to 4.82.

LUSTRE, submetallic. OPAQUE.

STREAK, brownish black. TENACITY, brittle.

COLOR, brownish black to steel gray.

BEFORE BLOWPIPE, ETC.—Infusible. With borax an amethystine bead. Soluble in hydrochloric acid, evolving chlorine and generally leaving gelatinous silica.

FIG. 344.

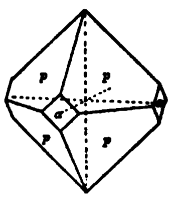


FIG. 345.

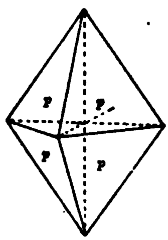
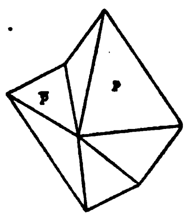


FIG. 346.



Braunite, $pp = 77° 45'$.

Hausmannite, $pp = 74° 34'$.

* *Mineral Resources of the United States*, 1902, p. 138.

Similar Species.—Resembles hausmannite, but has a darker streak and is harder.

Uses.—It occurs in large quantities in India and smaller amounts elsewhere, and is an ore of manganese.

HAUSMANNITE.

Composition.—Mn_3O_4. (Mn_2O_3 69.0, MnO 31.0 per cent.).

General Description.—Black granular strongly coherent masses occasionally in simple and twinned tetragonal pyramids which are more acute than those of braunite, $\dot{c} = 1.174$.

Physical Characters.—Opaque. Lustre, submetallic. Color, brownish black. Streak, chestnut brown. H., 5 to 5.5. Sp. gr., 4.72 to 4.85. Strongly coherent.

Before Blowpipe, Etc.—Infusible. Colors borax bead amethystine. Soluble in hydrochloric acid with evolution of chlorine.

Similar Species.—Differs from braunite in hardness, streak and absence of silica.

PYROLUSITE.—Black Oxide of Manganese.

Composition.—MnO_2, (Mn 63.2 per cent.).

General Description.—A soft black mineral of metallic lustre. Frequently composed of short indistinct crystals or radiated needles, but also found compact, massive, stalactitic, and as velvety crusts. It is also the common dendrites, Fig. 274. Usually soils the fingers. Frequently in alternate layers with psilomelane.

Physical Characters. H., 1 to 2.5. Sp. gr., 4.7 to 4.86.

Lustre, metallic or dull.	Opaque.
Streak, black.	Tenacity, rather brittle.
Color, black to steel gray.	

Before Blowpipe, Etc.—Infusible, becomes brown. Usually yields oxygen and a little water in closed tube. Colors borax bead amethystine. Soluble in hydrochloric acid with evolution of chlorine.

Similar Species.—Distinguished by its softness and black streak from other manganese minerals.

Remarks.—Pyrolusite results from the dehydration of manganite and the alteration of alabandite and rhodochrosite. It is usually with psilomelane, hematite, limonite or manganite.

By far the larger part of all that is mined in this country is obtained from Crimera, Va., Cartersville, Ga., and Batesville, Ark. Other deposits exist in California, Vermont and North Carolina. Large amounts are annually imported from Cuba. The purest material for use in glass making is obtained near Sussex, N. B., and from the Tenny Cape district, Nova Scotia.

USES.—Pyrolusite is used in the manufacture of chlorine and oxygen, and in the preparation of spiegeleisen. Also in coloring and decolorizing glass and as an oxidizing agent in varnishes, linseed oil, etc.

MANGANITE.

COMPOSITION.—MnO(OH), (Mn 62.4, O 27.3, H_2O 10.3 per cent.).

GENERAL DESCRIPTION.—Occurs in long and short prismatic

FIG. 347.

Manganite, Ilefeld, Hartz. N. Y. State Museum.

(orthorhombic) crystals often grouped in bundles with fluted or rounded cross-section and undulating terminal surface, rarely massive, granular or stalactitic.

Physical Characters, H., 4. Sp. gr., 4.2 to 4.4.

LUSTRE, submetallic. OPAQUE.
STREAK, reddish brown to black. TENACITY, brittle.
COLOR, steel gray to iron black.

BEFORE BLOWPIPE, ETC.—Like pyrolusite, but yields *decided* test for water and very little oxygen.

REMARKS.—Frequently formed by deposition from water. By alteration it forms other manganese minerals such as pyrolusite.

PSILOMELANE.—Black Hematite.

COMPOSITION.—Perhaps $MnO_2+(H_2O, K_2O$ or $BaO)$ or H_4MnO_5, with replacement by Ba or K.

GENERAL DESCRIPTION.—A smooth black massive mineral commonly botryoidal, stalactitic or in layers with pyrolusite. Never crystallized.

Physical Characters. H., 5 to 6. Sp. gr., 3.7 to 4.7.

LUSTRE, submetallic or dull. OPAQUE.
STREAK, brownish black. TENACITY, brittle.
COLOR, iron black to dark gray.

BEFORE BLOWPIPE, ETC.—Infusible.* In closed tube yields oxygen and usually water. Soluble in hydrochloric acid, with evolution of chlorine. A drop of sulphuric acid added to the solution will usually produce a white precipitate of barium sulphate.

SIMILAR SPECIES.—Distinguished from pyrolusite by its hardness, and from limonite by its streak.

REMARKS.—Its localities are the same as for pyrolusite, and the two minerals are usually mined together.

USES.—As for pyrolusite; the products, however, are less pure.

WAD.—Bog Manganese.

COMPOSITION.—Mixture of manganese oxides, with often oxides of metals other than manganese such as cobalt, copper and lead.

GENERAL DESCRIPTION.—Earthy to compact indefinite mixtures of different metallic oxides, in which those of manganese predominate. Dark brown or black in color; often soft and loose, but sometimes hard and compact.

PHYSICAL CHARACTERS.—Opaque. Lustre dull. Color brown to black. Streak brown. H., ½ to 6. Sp. gr., 3 to 4.26. Often soils the fingers.

BEFORE BLOWPIPE, ETC.—As for psilomelane, but often with strong cobalt or copper reactions.

USES.—Wad is used as a paint and in the manufacture of chlorine.

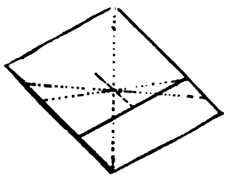
RHODOCHROSITE.

COMPOSITION. — $MnCO_3$, (MnO 61.7, CO_2 38.3 per cent.) with partial replacement by Ca, Mg or Fe.

GENERAL DESCRIPTION.—Rose pink to brownish red rhombohedral crystals, usually small and curved like dolomite. Frequently massive cleavable, or granular or compact. Less frequently botryoidal or incrusting.

* May become magnetic from impurities.

FIG. 348.



CRYSTALLIZATION. — Hexagonal. Scalenohedral class, p. 42. Axis $\dot{c} = .8184$. Angles as in siderite. Usual form a rhombohedron of 73°. Optically —.

Physical Characters. H., 3.5 to 4.5. Sp. gr., 3.3 to 3.6.

LUSTRE, vitreous to pearly. TRANSPARENT to opaque.

STREAK, white. TENACITY, brittle.

COLOR, light pink, rose red, brownish red and brown.

CLEAVAGE, parallel to rhombohedron.

BEFORE BLOWPIPE, ETC. — Infusible, but decrepitates violently and becomes dark colored.* In borax yields amethystine bead. Soluble in warm hydrochloric acid, with effervescence, slowly soluble in the cold acid.

SIMILAR SPECIES. — Distinguished from rhodonite by form, cleavage, effervescence and infusibility.

REMARKS. — Principally found in ore-veins, especially with ores of manganese and silver. On exposure, sometimes loses color or becomes spotted by oxide. Found at Mine Hill, N. J., Butte, Montana, Austin, Nev., and elsewhere. It is not mined, however, in this country. The only producing localities are Merionethshire, Wales, and Chevron, Belgium.

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* May become magnetic from impurities.

CHAPTER XXIII.

NICKEL AND COBALT MINERALS.

THE COBALT MINERALS.

THE cobalt minerals described are:

Sulphide	**Linnæite**	$(Co.Ni)_3S_4$	Isometric
Sulpharsenide	**Cobaltite**	$CoAsS$	Isometric
Arsenide	**Smaltite**	$(Co.Ni)As_2$	Isometric
Arsenate	*Erythrite*	$Co_3(AsO_4)_2.8H_2O$	Monoclinic

The metal cobalt has, as yet, no important use; the oxide is used to impart a blue color to glass and pottery. The chief commercial compound is SMALT, a cobalt glass, the cobalt replacing the calcium of ordinary glass. This is ground and used as a fine blue pigment, which is unaltered by exposure.

Cobalt blue and Rinmann's green are compounds of cobalt with alumina and zinc oxide respectively.

The extraction of cobalt from a nickeliferous matte is an elaborate chemical operation involving solution in hydrochloric acid, precipitation of manganese and iron as basic carbonates, and of other metals as sulphides, leaving a solution of chloride of nickel and cobalt. From these the cobalt is precipitated with great care, by means of calcium hypochlorite, as cobaltic hydroxide, after which the nickel is precipitated as hydroxide by lime-water. By using selected ores, mattes especially rich in cobalt may be obtained and for ordinary purposes the small nickel contents are neglected.

About 200 tons are annually produced.

LINNÆITE. — Cobalt Pyrites.

COMPOSITION. — $(Co.Ni)_3S_4$, often with some Fe or Cu replacing.

GENERAL DESCRIPTION. — A steel-gray metallic mineral usually in granular or compact masses intermixed frequently with chalcopyrite; also in small isometric crystals, usually the octahedron *p*, Fig. 349, or this with the cube *a*, Fig. 350.

* Cobalt is sometimes found in arsenopyrite. Asbolite is a black earthy oxide of cobalt and manganese.

FIG. 349.

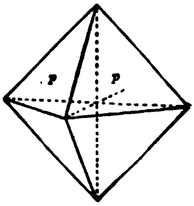
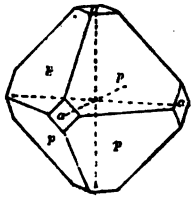


FIG. 350.



Physical Characters. H., 5.5. Sp. gr., 4.8 to 5.

LUSTRE, metallic. OPAQUE.

STREAK, nearly black. TENACITY, brittle.

COLOR, steel-gray, with reddish-tarnish.

CLEAVAGE, cubic imperfect.

BEFORE BLOWPIPE, ETC.—On charcoal fuses to a magnetic globule, and gives off fumes of sulphur dioxide. In borax bead gives a deep blue color, and with frequent replacement of borax the red bead of nickel may be obtained. Soluble in nitric acid to a red solution and with separation of sulphur.

REMARKS.—Occurs with other cobalt and nickel minerals and with chalcopyrite, pyrrhotite, bornite, at Mine La Motte, Mo., Lovelock's Station, Nev., and in a few other American localities.

USES.—Does not occur in large amounts, but is used as a source of both cobalt and nickel.

COBALTITE.—Cobalt Glance.

COMPOSITION.—CoAsS, (Co 35.5, As 45.2, S 19.3 per cent.)

GENERAL DESCRIPTION.—A silver white to gray metallic mineral resembling linnæite in massive state but in crystals differing in that the forms are the pyritohedron *e*, and cube *a*, and these combined, Fig. 353.

FIG. 351.

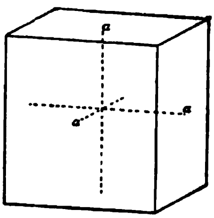


FIG. 352.

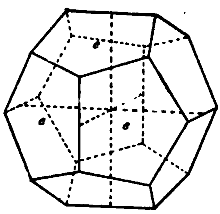
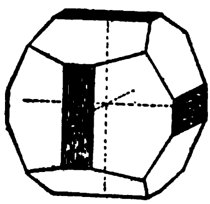


FIG. 353.



Physical Characters. H., 5.5. Sp. gr., 6 to 6.1.

Lustre, metallic.	Opaque.
Streak, black.	Tenacity, brittle.
Color, silver white to gray.	Cleavage, cubic.

Before Blowpipe, Etc. — On charcoal fuses to a magnetic globule and evolves white fumes with garlic odor. Unaltered in closed tube. Soluble in warm nitric acid to rose-red solution, with residue of sulphur and arsenous oxide.

Uses. — It is used in the manufacture of smalt and in porcelain painting.

SMALTITE.

Composition. — $(Co.Ni)As_2$, varying widely in proportion of cobalt and nickel, and usually containing some iron also.

General Description.—A tin-white to steel-gray metallic mineral resembling linnæite and cobaltite. Usually occurs granular massive, but also in isometric crystals, especially modified cubes with curved faces.

Physical Characters. H., 5.5 to 6. Sp. gr., 6.4 to 6.6.

Lustre, metallic.	Opaque.
Streak, black.	Tenacity, brittle.
Color, tin-white to steel-gray.	Cleavage, octahedral.

Before Blowpipe, Etc.—On charcoal fuses, yields white fumes with garlic odor and leaves a magnetic residue, which, when oxidized in contact with frequently replaced borax, yields successively slags colored by iron, cobalt, nickel and possibly by copper. In closed tube yields arsenical mirror. Soluble in nitric acid to a red to green solution according to proportion of cobalt and nickel. Partially soluble in hydrochloric acid, especially so after fusion, but yields no voluminous precipitate of yellow arsenic sulphide, as does arsenopyrite when similarly treated.

Similar Species.—Differs from linnæite and cobaltite in cleavage, specific gravity and blowpipe reactions. Differs from most arsenopyrite and tetrahedrite in the cobalt blue slags which it yields. It can best be distinguished from cobaltiferous arsenopyrite by the reaction in acids after fusion.

Remarks.—By oxidation produces arsenates of cobalt (erythrite) and nickel (annabergite). Occurs in veins with other metallic minerals, especially ores of copper, silver, nickel and cobalt. Especially abundant in the nickel mines of Saxony. Found at Chatham, Ct., Franklin Furnace, N. J., and in California.

USES. — It is the chief ore of cobalt.

Chloanthite, $NiAs_2$. — A tin, white to steel-gray metallic mineral which resembles smaltite, and by replacement of nickel by cobalt gradually grades into that mineral.

ERYTHRITE.

COMPOSITION.—$Co_3(AsO_4)_2.8H_2O$, (CoO 37.5, As_2O_5 38.4, H_2O 24.1 per cent.).

GENERAL DESCRIPTION.—Groups of minute peach red or crimson crystals forming a drusy or velvety surface. Also in small globular forms or radiated or as an earthy incrustation of pink color.

PHYSICAL CHARACTERS. — Translucent. Lustre, adamantine or pearly. Color, crimson, peach red, pink and pearl gray. Streak, paler than color. H., 1.5 to 2.5. Sp. gr., 2.91 to 2.95. Flexible in laminæ.

BEFORE BLOWPIPE, ETC. — On charcoal fuses easily, evolves white fumes with garlic odor, and leaves a magnetic residue, which imparts the characteristic blue to borax bead. Soluble in hydrochloric acid to a light red solution.

THE NICKEL MINERALS.

The nickel minerals described are:

Sulphides	**Millerite**	NiS	Hexagonal
	Pentlandite	$(Fe.Ni)S$	Isometric
Arsenide	**Niccolite**	$NiAs$	Hexagonal
Arsenate	*Annabergite*	$Ni_3(AsO_4)_2 \cdot 8H_2O$	Monoclinic
Silicate	**Garnierite**	$H_2(Ni.Mg)SiO_4 \cdot H_2O$	

Metallic nickel is extensively used in different alloys, and, indeed, was first obtained as a residual alloy with copper, iron and arsenic, in the manufacture of smalt. This alloy was called German silver or nickel silver and largely used in plated silverware. Later, a large use for nickel was found in coins, the United States Mint alone using nearly one million pounds between 1857 and 1884. In this alloy copper is in large proportion, the present five cent piece being 25 per cent. nickel, 75 per cent. copper, and in other coins the percentage of copper being still greater. The most extensive application of nickel at present is in the manufac ture of nickel steel for armor plates and other purposes. The uses of nickel steel are continually increasing, as the metal has some excellent properties possessed by no other alloy. To a limited extent nickel is used in a nickel-copper alloy for casing rifle bullets. An alloy of iron and nickel containing 30 per cent. of nickel is non-magnetic and is used in electric heaters and in parts of other electrical apparatus.

A sulphate of nickel and ammonium is also manufactured in large amounts for use in nickel plating.

The nickel of commerce is nearly all obtained either from the garnierite of New Caledonia or from the deposit of nickel-bearing sulphides at Sudbury, Ontario. The garnierite is smelted in a low blast furnace, with coke and gypsum, and the matte of nickel, iron and sulphur thus produced is alternately roasted and fused with sand, in a reverberatory furnace, until nearly all the iron has been removed. The nickel sulphide, by oxidation, is converted into oxide.

Nickel oxide is obtained from the pyrrhotite and chalcopyrite of Sudbury, Canada. The ore is first roasted to remove much of the sulphur, and is then smelted, together with nickel-bearing slags of previous operations. A nickel matte carrying much copper and some iron is produced through which air is blown in a silica-lined Bessemer converter and most of the iron is carried into the slag. A matte, rich in nickel and copper, results. This may be directly roasted and reduced by carbon to produce nickel-copper alloys for the manufacture of German silver. In order to separate the nickel the concentrated matte is fused with sodium sulphate and coke, after which the melted sulphides are allowed to settle. Under these conditions the copper and iron sulphides form a very fluid mass with the soda, and, with some nickel, rise to the top while the lower portions of the mass are highly nickeliferous. The two layers are separated and each is re-treated in much the same manner. The nickel sulphide resulting is partially roasted and is fused with sand, by means of which most of the iron is removed as a silicate in the slag. The nickel sulphide remaining is by oxidation converted into the oxide. The oxide is sold directly to steel makers or may be reduced to metal by mixing with charcoal and heating, white hot, in a graphite crucible.

The world's annual output of nickel is about 10,000 short tons. In 1903 the U. S. produced* 11,200,000 pounds almost wholly from foreign ores.

Nickel is now successfully refined by electrolysis, but the details of the process are jealously guarded. It is doubtful, however, if nickel can be separated from cobalt in this manner, although most other impurities are removed.

The Mond process for the extraction of nickel from its ore and

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* *Eng. and Min. Jour.*, 1904, p. 4.

or its separation from cobalt promises to become important. The process is based on the discovery that when carbon monoxide is passed over heated nickel, volatile nickel carbonyl, $Ni(CO)_4$, is formed. As cobalt does not react in this way, the separation of nickel from cobalt is easily accomplished. The reconversion of the nickel carbonyl into nickel and carbon monoxide is a simple operation.

MILLERITE. — Capillary Pyrites.

COMPOSITION. — NiS, (Ni 64.4 per cent.).

GENERAL DESCRIPTION. — A brass-colored mineral with metallic lustre, especially characterized by its occurrence in hair-like or needle crystals, often interwoven or in crusts made up of radiating needles.

Physical Characters. H., 3 to 3.5. Sp. gr., 5.3 to 5.65.

LUSTRE, metallic. OPAQUE.

STREAK, greenish-black. TENACITY, crystals elastic.

COLOR, brass or bronze yellow.

BEFORE BLOWPIPE, ETC.—On charcoal spirts and fuses to a brittle magnetic globule, which will color borax red. Soluble in aqua regia to a green solution, from which potassium hydroxide precipitates a green nickelous hydroxide which is again soluble in ammonia to a blue solution.

REMARKS.—Millerite has probably been formed in the same way as pyrite. It is probable that the nickel in pyrrhotite is there as millerite. Other associates are siderite, hematite and dolomite. In the United States it has been obtained chiefly from the Lancaster Gap mine, in Pennsylvania, and at Antwerp, N. Y.

USES.—It is a valued ore of nickel.

PENTLANDITE.

COMPOSITION. — (Fe.Ni)S.

GENERAL DESCRIPTION. — Light bronze-yellow, granular masses of metallic lustre. Often showing octahedral cleavage or parting. Usually with chalcopyrite or pyrrhotite.

Physical Characters. H., 3.5–4. Sp. gr., 4.6–5.

LUSTRE, metallic. OPAQUE.

STREAK, black. TENACITY, brittle.

COLOR, light bronze yellow. NOT MAGNETIC.

Before Blowpipe, Etc. — Fuses readily to a magnetic globule which reacts for iron and nickel.

Uses. — Occurs at Sudbury, Ontario, with pyrrhotite and chalcopyrite and is mined for nickel of which it is an important ore.

NICCOLITE.—Copper Nickel.

Composition.—NiAs, (Ni 43.9 per cent.). As is replaced to some extent by Sb or S, and Ni by Fe or Co.

General Description.—A massive mineral of metallic lustre, characteristic pale copper red color and smooth impalpable structure. Sometimes the copper-red kernel has a white metallic crust. Occasionally occurs in small indistinct hexagonal crystals.

Physical Characters. H., 5 to 5.5. Sp. gr., 7.3 to 7.67.

Lustre, metallic.	Opaque.
Streak, brownish-black.	Tenacity, brittle.
Color, pale copper red with dark tarnish.	

Before Blowpipe, Etc.—On charcoal fuses easily, giving off white fumes with garlic odor and leaving a magnetic residue, which will color borax bead red and sometimes blue, in which case the borax must be renewed until the cobalt is all removed. In open tube yields a white sublimate and a yellowish-green pulverulent residue. Soluble in concentrated nitric acid to a green solution, which may be tested as under millerite.

Similar Species.—Differs from copper in hardness, black streak and brittleness.

Remarks.—Its most abundant American localities are at Lovelock's, Nevada, and Tilt Cove, Newfoundland. Also obtained at Chatham, Conn., and Thunder Bay, Lake Superior.

Uses.—It is an important ore of nickel.

ANNABERGITE.—Nickel Bloom.

Composition.—$Ni_3(AsO_4)_2.8H_2O$, (NiO 37.4 As_2O_5 38.5, H_2O 24.1 per cent.).

General Description.—Pale apple-green crusts, and occasionally very small hair-like crystals. Usually occurs on niccolite or smaltite.

Physical Characters.—Dull. Color, apple-green. Streak, greenish-white. H., 1.

Before Blowpipe, Etc.—On charcoal, fuses easily to a magnetic button, and becomes dull and yellow during fusion, evolving garlic odor. In closed tube, yields water and darkens. With borax, gives red bead. Soluble in nitric acid.

Remarks.—Results from the oxidation of niccolite or smaltite in moist air.

GARNIERITE.—Noumeite.

COMPOSITION.—$H_2(Ni.Mg)SiO_4 + H_2O$ or $2(Ni.Mg)_5Si_4O_{13}.3H_2O$.

GENERAL DESCRIPTION.—Loosely compacted masses of brilliant dark-green to pale-green mineral, somewhat unctuous. Structure often small mammelonated, with dark-green, varnish-like surfaces, enclosing dull green to yellowish ochreous material. Easily broken and earthy.

Physical Characters. H., 2 to 3. Sp. gr., 2.27 to 2.8.

LUSTRE, varnish-like, to dull. OPAQUE.

STREAK, light green to white. TENACITY, friable.

COLOR, deep green to pale greenish-white.

UNCTUOUS, adheres to the tongue.

BEFORE BLOWPIPE, ETC. — Infusible, decrepitates and becomes magnetic. In closed tube yields water. Borax bead gives nickel reaction. Partially soluble in hydrochloric and nitric acids.

SIMILAR SPECIES.—Differs from malachite and chrysocolla in structure and unctuous feeling. Differs from serpentine in deep color and nickel reaction.

REMARKS.—Occurs in New Caledonia in veins in serpentine, with chromite and talc. Possibly derived from a nickel-bearing chrysolite. Deposits are also known at Riddles, Oregon and Webster, N. C.

USES.—It is now the chief source of nickel.

CHAPTER XXIV.

ZINC AND CADMIUM MINERALS.

THE ZINC MINERALS.

THE zinc minerals described are:

Sulphide	**Sphalerite**	ZnS	Isometric
Oxide	**Zincite**	ZnO	Hexagonal
Sulphate	*Goslarite*	$ZnSO_4.7H_2O$	Orthorhombic
Carbonates	**Smithsonite**	$ZnCO_3$	Hexagonal
	Hydrozincite	$ZnCO_3.2Zn(OH)_2$	
Silicates	**Willemite**	Zn_2SiO_4	Hexagonal
	Calamine	$(ZnOH)_2SiO_3$	Orthorhombic

The important ores of zinc are sphalerite, smithsonite, and calamine; and, in New Jersey, willemite and zincite occur in quantity sufficient to be considered ores. A large amount of zinc oxide is also made from franklinite which is described under the iron minerals.

In this country, Missouri, Kansas, Indiana and Illinois yield most of the zinc ore, although other important regions are Pennsylvania, New Jersey and Virginia. The western ore contains lead ore, from which it is separated by concentration. In all, in 1903, this country produced 156,318 tons of metallic zinc and 59,810 tons of zinc oxide were manufactured,* besides exporting 37,619 tons of zinc ore.

The principal uses of metallic zinc are in galvanizing iron wire or sheets and in manufacturing brass. A smaller amount is made into sheet zinc and zinc dust.

Metallic zinc is obtained by distillation of its roasted ores with carbon. The sulphide and carbonate, by roasting, are converted into oxide, and the silicates are calcined to remove moisture. The impure oxides, or the silicate, are mixed with fine coal and charged in tubes or vessels of clay, closed at one end and connected at the other end with a condenser. These are submitted to a gradually increasing temperature, by which the ore is reduced to metallic

* *Engineering and Mining Journal*, 1904, p. 4.

zinc, and, being volatile, distills, and is condensed. Apparently successful processes are now in use for the direct deposition of zinc from its ores by electrolysis.

Zinc oxide, ground in oil, constitues the paint zinc white. The oxide may be made from the metal by heating it to a temperature at which the zinc takes fire and drawing the fumes into suitable condensers; or, as in this country, it may be made directly from the ore.

SPHALERITE. — Blende, Zinc Blende, Black-Jack.

COMPOSITION. — ZnS (Zn, 67 per cent.). Often contains Cd, Mn, Fe.

GENERAL DESCRIPTION. — A mineral of resinous lustre shading in color from yellow through brown to nearly black and transparent to translucent. It occurs frequently cleavable massive but also in crystals and in compact fine-grained masses or alternate concentric layers with galenite.

FIG. 354.

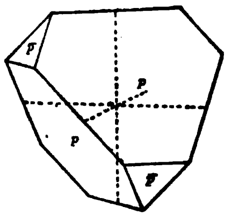


FIG. 355.

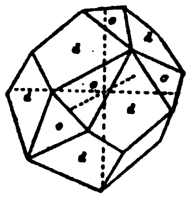
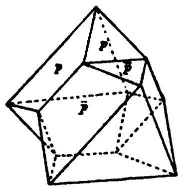


FIG. 356.



CRYSTALLIZATION. — Isometric. Hextetrahedral class, p. 56. Usually the dodecahedron d with the tetrahedron p and a modifying tristetrahedron $o = (a : 3a : 3a)$; $\{311\}$. Fig. 355, usually with rounded faces. More rarely the + and − tetrahedron, Fig. 354, and sometimes in twin crystals like Fig. 356.

Index of refraction for yellow light, 2.3692.

Physical Characters. H., 3.5 to 4. Sp. gr., 3.9 to 4.1.

LUSTRE, resinous. TRANSPARENT to translucent.

STREAK, white to pale brown. TENACITY, brittle.

COLOR, yellow, brown, black; rarely red, green or white.

CLEAVAGE, parallel to rhombic dodecahedron (angles 120° and 90°).

BEFORE BLOWPIPE, ETC.—On charcoal fuses with difficulty, but readily yields a sublimate, sometimes brown at first from cadmium

and later yellow while hot, white when cold and becoming bright green if moistened and ignited with cobalt solution. With soda gives a sulphur reaction. Soluble in hydrochloric acid with effervescence of hydrogen sulphide.

SIMILAR SPECIES.—Smaller crystals sometimes slightly resemble garnet or cassiterite, but are not so hard.

REMARKS.—Sphalerite has probably been formed by precipitation from water by H_2S or with the aid of decaying organic matter. By oxidation it changes to sulphate which in turn may be decomposed by carbonates and silicates forming carbonates and silicates of zinc. Sphalerite is a common associate of lead and silver ores and is detrimental, as it makes their treatment more difficult. It also occurs with other sulphides and with other zinc ores. It is mined in southwest Missouri, at Friedensville, Pa., in the southwestern part of Wisconsin, at Pulaski, Va., and at other places. In small quantities it is of very common occurrence.

USES.—It is an important ore of zinc and also is the source of most of the cadmium of commerce.

Goslarite. — $ZnSO_4.7HO$, is formed by the oxidation of sphalerite in damp locations. It is a white or yellowish earthy mineral with nauseous astringent taste. Usually an incrustration or mass shaped like the original sphalerite or in stalactites. Rarely needle-like orthorhombic crystals.

ZINCITE.—Red Zinc Ore.

COMPOSITION.—ZnO, (Zn 80.3 per cent.) with usually some Mn or Fe.

GENERAL DESCRIPTION.—A deep red to brick-red adamantine mineral occurring in lamellar or granular masses, either in calcite or interspersed with grains and crystals of black franklinite and yellow to green willemite. A few hexagonal pyramids have been found.

Physical Characters. H., 4 to 4.5. Sp. gr., 5.4 to 5.7.

LUSTRE, sub-adamantine. TRANSLUCENT.

STREAK, orange yellow. TENACITY, brittle.

COLOR, deep red to orange red.

CLEAVAGE, basal and prismatic yielding hexagonal plates.

BEFORE BLOWPIPE, ETC.—Infusible. On charcoal gives reactions for zinc as described under sphalerite. In closed tube blackens, but is again red on cooling. With borax usually gives amethystine bead. Soluble in hydrochloric acid without effervescence.

SIMILAR SPECIES.—Differs from realgar and cinnabar in its associates, infusibility and slow volatilization.

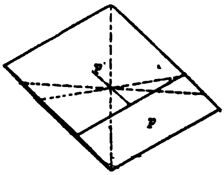
REMARKS.—Occurs in quantity only in Sussex County, N. J., at the franklinite localities and is smelted with the associated franklinite, willemite, etc., and the zinc recovered.

SMITHSONITE. — Dry Bone, Calamine.

COMPOSITION. — $ZnCO_3$ (ZnO, 64.8 ; CO_2, 35.2 per cent.).

GENERAL DESCRIPTION. — Essentially a white vitreous mineral but often colored yellowish or brownish by iron. Structure stalactitic or botryoidal, or with drusy crystal surface; also in chalky cavernous masses and granular. Sometimes of decided colors, as deep green or bright yellow, from copper or cadmium respectively.

FIG. 357.



CRYSTALLIZATION.—Hexagonal. Scalenohedral class, p. 42. Axis $\dot{c}=0.8063$. Usually small rhombohedrons of 73°, Fig. 357, like those of siderite.

Optically —.

Physical Characters. H., 5. Sp. gr., 4.3 to 4.5.

LUSTRE, vitreous to dull. TRANSLUCENT to opaque.

STREAK, white. TENACITY, brittle.

COLOR, shades of white, more rarely yellow, green, blue, etc.

CLEAVAGE, parallel to rhombohedron (107°).

BEFORE BLOWPIPE, ETC.—Infusible but readily yields white sublimate on coal, often preceded by brown of cadmium. The sublimate becomes yellow when heated and becomes bright green when moistened with cobalt solution and then heated. Soluble in acids with effervescence.

SIMILAR SPECIES.—Distinguished from calamine by its effervescence and from other carbonates by its hardness.

REMARKS.—Smithsonite is a secondary product formed usually by action of carbonated waters on other zinc ores and sometimes by atmospheric action. It occurs with the other ores of zinc, especially calamine, and with ores of lead, copper and iron. In this country it is most abundant in the Missouri, Virginia and Wisconsin zinc regions.

USES.—Smithsonite, being easily reduced with little fuel, is a valuable zinc ore, but as it is found chiefly near the surface, the deposits have been nearly exhausted.

HYDROZINCITE.—Zinc Bloom.

COMPOSITION.—$ZnCO_3 \cdot 2Zn(OH)_2$, (ZnO 75.3, CO_2 13.6, H_2O 11.1 per cent.).

GENERAL DESCRIPTION.—Usually a soft white incrustation upon other zinc minerals, or as dazzling white stalactites, or earthy and chalk like.

PHYSICAL CHARACTERS.—Opaque. Lustre, dull or pearly. Color, pure white to yellowish. Streak shining white. H., 2 to 2.5. Sp. gr., 3.58 to 3.8.

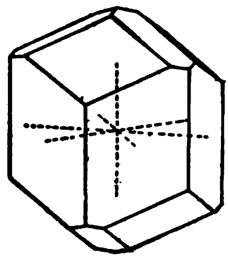
BEFORE BLOWPIPE, ETC. — Infusible. Coats the coal like smithsonite. Yields water in closed tube. Soluble in cold dilute acids with effervescence.

WILLEMITE. — Troostite.

COMPOSITION. — Zn_2SiO_4, (ZnO, 72.9; SiO_2, 27.1); often with much manganese replacing zinc.

GENERAL DESCRIPTION. — A greenish yellow to apple green or sulphur yellow mineral when pure, but often flesh red or brownish from manganese or iron. Usually occurs granular, but also as hexagonal crystals and massive. The New Jersey variety is known by its associates, franklinite and zincite.

FIG. 358.



Franklin Furnace, N. J.

CRYSTALLIZATION. — Hexagonal. Class of third order rhombohedron, p. 48. Axis $\dot{c}$ = 0.6775. Long slender prisms of yellowish color and coarse thick prisms of flesh red color occur at Franklin Furnace; the Altenberg crystals are small and brown in color.

Physical Characters. H., 5.5. Sp. gr., 3.89 to 4.2.

LUSTRE, resinous.	TRANSPARENT to opaque.
STREAK, nearly white.	TENACITY, brittle.

COLOR, greenish to sulphur yellow, apple green, white, flesh red.
CLEAVAGE, basal and prismatic.

BEFORE BLOWPIPE, ETC. — Fusible in thin splinters only upon the edges to a white enamel. On heating with cobalt solution becomes blue. On charcoal with soda and a little borax yields the zinc coat. Soluble in hydrochloric acid leaving a gelatinous residue. Specimens from Franklin, N. J., phosphoresce brilliantly under the influence of radium, actinium, ultra-violet and X-rays.

SIMILAR SPECIES.—Red crystals resemble apatite but differ in terminations, rhombohedral in willemite but pyramidal in apatite. Willemite is also heavier than apatite and gelatinizes.

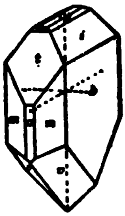
USES.—In association with the other minerals of Franklin, N. J., it constitutes a valuable ore of zinc. This, however, is its only important locality.

CALAMINE.—Electric Calamine.

COMPOSITION.—$(ZnOH)_2SiO_3$, (ZnO, 67.5; SiO_2, 25.0; H_2O, 7.5 per cent.).

GENERAL DESCRIPTION. — A white or brownish white vitreous mineral frequently with a drusy surface or in radiated groups of crystals, the free ends of which form a ridge or cockscomb, Fig. 264, and more rarely, small distinct transparent crystals. It occurs also granular, stalactitic, botryoidal and as a constituent of some clays.

FIG. 359.



Altenberg.

CRYSTALLIZATION.— Orthorhombic. Hemimorphic class, p. 35. Axes $\breve{a} : \bar{b} : c = 0.783 : 1 : 0.478$. The crystals are usually tabular, the broad face being the brachypinacoid b, while the prism m is relatively small. v is the pyramid $2\breve{a} : \bar{b} : 2c$; $\{121\}$.

Optically +, with acute bisectrix vertical. $2E$ for yellow light = 78° 39′.

Physical Characters. H., 4.5 to 5. Sp. gr., 3.4 to 3.5.

LUSTRE, vitreous to pearly. OPAQUE to transparent.
STREAK, white. TENACITY, brittle.
COLOR, yellow to brown, white, colorless, rarely blue or green.
Cleavage, prismatic.

BEFORE BLOWPIPE, ETC.—Fusible only in finest splinters. With soda and borax, on charcoal yields a white coating, which is made bright green by heating with cobalt solution. In closed tube, yields water. With acids, dissolves, leaving a gelatinous residue.

SIMILAR SPECIES.—It is softer than prehnite, harder than cerussite, and gelatinizes with acids. It differs from willemite in water reaction, and from stilbite in difficulty of fusion.

REMARKS.—Calamine seems to be formed by the action of hot silica bearing waters upon other zinc ores, especially sphalerite. It is often disseminated through a clay, from which it is gradually segregated and crystallized. Its most important locality in America is at Granby, Mo. It is also found in quantity at Sterling Hill, N. J., and Bertha, Va. Abroad, it is exported from Greece, and is mined in large amounts in Silesia and the Rhenish Provinces of Germany.

USES. — It is a valuable ore of zinc, usually free from volatile impurities.

THE CADMIUM MINERALS.

The only cadmium mineral is the *sulphide*, GREENOCKITE, CdS. About five tons per year of cadmium are obtained from the Si-

lesian zinc ores. The first fumes are redistilled and finally reduced with carbon. The metal is used in fusible alloys and certain forms of silver plating. The sulphide forms a splendid yellow pigment unaltered by exposure.

GREENOCKITE.

COMPOSITION.—CdS, (Cd, 77.7 per cent.)

GENERAL DESCRIPTION.—Usually a bright yellow powder upon sphalerite, or a yellow coloration *in* smithsonite. Very rarely as small hemimorphic hexagonal crystals. $\dot{c} = 0.8111$.

PHYSICAL CHARACTERS.—Translucent. Lustre earthy or adamantine. Color yellow to orange yellow or bronze yellow. Streak orange yellow. H., 3 to 3.5. Sp. gr., 4.9 to 5.0.

BEFORE BLOWPIPE, ETC.—Infusible, but is easily volatilized in the reducing flame, coating the coal with a characteristic brown coat and a iridescent tarnish. In closed tube, turns carmine red on heating, but is yellow on cooling. Soluble in strong hydrochloric acid, with effervescence of hydrogen sulphide.

CHAPTER XXV.

TIN, TITANIUM, AND THORIUM MINERALS.
THE TIN MINERALS.

THE minerals described are:

Sulphide	*Stannite*	(Cu.Sn.Fe)S	Isometric
Oxide	**Cassiterite**	SnO_2	Tetragonal

Tin is also found as an occasional constituent of tantalite and other tantalates.

Cassiterite is the only ore of tin, and while it occurs or has been reported from nine or ten states, no tin is now produced* in this country. The world's supply of tin, amounting yearly to about 90,000 long tons, comes chiefly from the East India Islands, Tasmania, Bolivia and Cornwall, England.

The principal use of tin is for the manufacture of tin plate — sheet-iron coated with tin — which is used for making cans, household utensils, etc. Tin is also largely used in alloys, such as bronze, bell metal, pewter, solder and tin amalgam. Tinfoil is also made from it.

The ore as mined is first separated from gangue and impurities by washing, jigging, etc., and if necessary, is then calcined or roasted, to remove volatile elements, such as sulphur, arsenic, antimony.

The concentrated and purified ore may then be smelted with carbon in a shaft furnace. The modern practice is, however, to smelt the ore for several hours in a reverberatory furnace with coal. The liquid tin is drawn off and the slags are resmelted at a higher temperature, frequently requiring the addition of iron or of lime to aid in the separation of the tin, which they still contain. The impure metal obtained is slowly heated to a temperature but little above the melting point of tin; comparatively pure tin separates and this is further purified by oxidation. This oxidation is accomplished either by forcing green wood under the liquid metal causing

* The Temescal mines of California produced about 120 tons from 1890 to 1892 but have since been unproductive.

violent agitation or by repeatedly pouring the melted tin in a thin stream from ladles. Tin may also be refined by electrolysis.

STANNITE.—Tin Pyrites.

COMPOSITION.—(Cu.Sn.Fe)S. Uncertain.

GENERAL DESCRIPTION.—A massive, granular mineral, of metallic lustre and steel-gray color. It is often intermixed with the yellow chalcopyrite.

PHYSICAL CHARACTERS.—Opaque. Lustre metallic. Color steel gray to nearly black. Streak black. H = 4. Sp. gr., 4.5 to 4.52. Brittle.

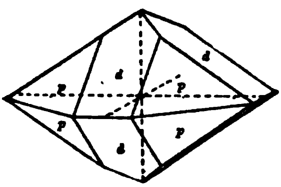
BEFORE BLOWPIPE, ETC.—In the reducing flame fuses. In the oxidizing flame yields SO_2, and is covered by white oxide, which becomes bluish-green when heated with cobalt solution. Soluble in nitric acid to a green solution, with separation of sulphur and oxide of tin. With soda, gives sulphur reaction.

CASSITERITE.—Stream Tin. Tin Stone.

COMPOSITION.—SnO_2, (Sn 78.6 per cent.), and usually with some Fe_2O_3, and sometimes Ta_2O_5, As_2O_5, SiO_2 or Mn_2O_3.

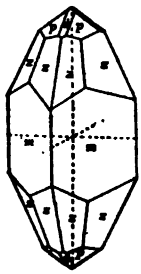
GENERAL DESCRIPTION.—A hard and heavy brown to black mineral occurring either in brilliant adamantine crystals or more frequently in dull botryoidal and kidney-shaped masses and rounded pebbles, often with a concentric or fibrous radiated structure.

FIG. 360.



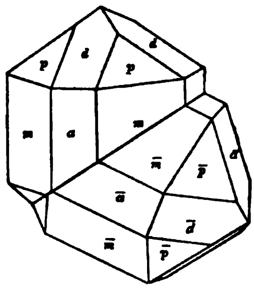
Stoneham, Me.

FIG. 361.



Cornwall, Eng.

FIG. 362.



Zinnwald.

CRYSTALLIZATION. — Tetragonal. Axis $c = 0.672$. Common forms are the unit first and second order pyramids and prisms p, a, m, and d, and the ditetragonal pyramid $z = (a : \frac{3}{2}a : 3c)$; $\{321\}$. Supplement angles $pp = 58° 19'$; $dd = 46° 28'$; $mz = 24° 59'$.

Frequently twinned parallel to the second order pyramid, Fig. 362.

Optically + with high indices of refraction 1.996 and 2.093.

Physical Characters. H., 6 to 7. Sp. gr., 6.8 to 7.1.

LUSTRE, adamantine to dull. OPAQUE to translucent.

STREAK, white or pale brown. TENACITY, brittle.

COLOR, brown to nearly black, sometimes red, gray, or yellow.
CLEAVAGES, indistinct pyramidal and prismatic.

BEFORE BLOWPIPE, ETC.—Infusible, but in powder becomes yellow and luminous. With cobalt solution the powder or any sublimate is made bluish green. On charcoal with soda may be reduced, yielding metallic button and a faint white sublimate close to the assay. Insoluble in acids and almost so in salt of phosphorus or borax in which it usually gives some manganese or iron reaction.

VARIETIES.

Tin Stone.—Crystals and granular masses.

Wood Tin.—Masses with concentric structure, the zones being of different color and internally fibrous.

Stream Tin.—Rounded pebbles and grains found in alluvial deposits.

SIMILAR SPECIES.—The high specific gravity distinguishes it from silicates which it resembles, and the infusibility and insolubility distinguish it from wolframite, etc.

REMARKS.—Cassiterite is found in veins in granite, gneiss, mica, schist and similar rocks with quartz, wolframite and scheelite, and also with certain sulphides and oxides. It occurs also in alluvial deposits, as stream tin. It is practically unchanged by atmospheric influences. The East Indian settlements of Malacca, Banca and Bilitong are the greatest producers of tin ore. They are closely followed by the mines in New South Wales, Queensland and Tasmania. Tin is also mined in large quantities at the ancient localities in Cornwall, England. In America the chief localities are in the Harney Peak region in South Dakota; near Temescal, California, and at Durango, Mexico. It has been found also in New Hampshire, Virginia, Maine, Massachusetts, Alabama, Wyoming and Montana but has not yet been obtained from any American locality in quantity sufficient to be called important.

USES.—All tin is made from cassiterite. The artificial oxide is used as a polishing powder.

THE TITANIUM MINERALS.

The minerals described are:

Oxides	**Rutile**	TiO_2	Tetragonal
	Octahedrite	TiO_2	"
	Brookite	TiO_2	Orthorhombic

Titanium is also a constituent of ilmenite and titanite, elsewhere described, and occurs in some other minerals.

Oxide of titanium is used to impart an ivory-like appearance to

porcelain, but otherwise is of no commercial importance. A few hundred pounds only are marketed each year in the United States.

The metal is only produced as a chemical curiosity or for the study of its properties. It is prepared by the reduction of its oxide by carbon at the highest available temperature of the electric furnace. In the form thus obtained it carries a small percentage of carbon, is the most infusible of metals and almost equals the diamond in hardness.

RUTILE. — Nigrine.

COMPOSITION.—TiO_2. (Ti 61 per cent.).

GENERAL DESCRIPTION.—Brownish red to nearly black prismatic crystals often included in other minerals in hair-like or needle-like penetrations. Also coarse crystals embedded in quartz, feldspar, etc., or in parallel and crossed and netted needles upon hematite or magnetite. Occasionally massive when black and iron bearing.

FIG. 363.

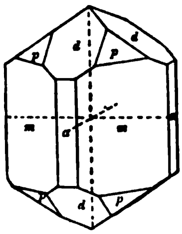
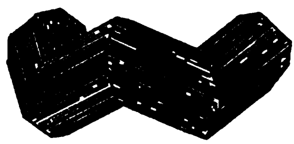


FIG. 364.

Magnet Cove, Ark.

FIG. 365.



CRYSTALLIZATION.— Tetragonal. Axis $c = 0.644$. Very close to cassiterite in angles and forms. Usual combinations are unit first and second order pyramids, p and d, and first and second order prisms, m and a. Often twinned in knees, Fig. 365, and rosettes, Fig. 364. As fine hair-like inclusions, Fig. 258. Prisms often striated vertically.

Supplement angles $pp = 56° 52'$; $dd = 45° 2'$.

Optically + with very high indices of refraction 2.616 and 2.902 for yellow light.

Physical Characters. H., 6 to 6.5, Sp. gr., 4.15 to 4.25.

LUSTRE, adamantine to nearly metallic. OPAQUE to transparent.

STREAK, white, pale brown. TENACITY, brittle.

COLOR, reddish brown, red, black, deep red when transparent.

CLEAVAGES, prismatic and pyramidal.

Before Blowpipe, Etc. — Infusible. In salt of phosphorus dissolves *very* slowly in the oxidizing flame to a yellow bead which becomes violet in the reducing flame. Insoluble in acids.

Similar Species. — It is redder and of lower specific gravity than cassiterite. The nearly metallic lustre, weight and infusibility separate it from garnet, tourmaline, vesuvianite, and pyroxene.

Remarks. — Widely distributed and associated with many minerals in which it is usually embedded. Little altered by atmospheric influences. Found in many American localities; prominent among them are Nelson Co., Va., Graves Mountain, Ga., Warwick, N. Y., Warren, Me., and Magnet Cove, Ark.

Uses. — Rutile is used to color porcelain yellow and to give the desired bluish white tint to artificial teeth.

Octahedrite. — TiO_2. In small pyramidal tetragonal crystals $\dot{c} = 1.777$. Either black opaque and nearly metallic, or brown translucent and adamantine.

Brookite = TiO_2. Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c} = 0.842 : 1 : 0.944$. Either brown translucent crystals which are thin and tabular, or black opaque crystals of varied habit.

THE THORIUM MINERALS.*

The minerals described are:

Phosphate	**Monazite**	(Ce, La, Di)PO_4,	Monoclinic
Silicate	*Thorite*	$ThSiO_4$,	Tetragonal

The oxide of thorium, thoria, has become very important of late years from its property of emitting intense white light when held in the flame of a Bunsen gas burner. The mantle of the Welsbach incandescent gas lamp consists of about 99 per cent. of thorium oxide with one per cent. of cerium oxide. The price of thoria has recently been greatly reduced owing to competition and improved methods of production and to the low price of Brazilian monazite.

The chief source of thoria is the phosphate of cerium mineral, monazite. This mineral carries salts of thorium as impurities and in quantities varying from traces to as much as 18.5 per cent. of thorium oxide. The mineral thorite is also employed in the production of thoria, but, although it contains over 20 per cent. of the oxide, it is much more difficult to obtain in quantity.

Monazite sand occurs in Brazil in immense deposits, certain

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* The following minerals also are usually rich in thoria and would be valuable if found in quantity: Gummite (0–42 per cent.), mackintoshite (45–46 per cent.), æschynite (15–17 per cent.), zirkelite (7–8 per cent.), tscheffkinite (0–21 per cent.), yttrialite (12 per cent.), caryocerite (13–14 per cent.), euxenite (0–6 per cent.), pyrochlore (8 per cent.).

beaches consisting of 90 per cent. of monazite. The production of the United States is increasing and in 1902 was 802,000 pounds,* principally from North Carolina.

Thoria is manufactured by methods which are carefully guarded. It is stated that the method usually employed is to decompose the monazite sand in hot sulphuric acid (1 : 1). The sulphates dissolved in water are converted into oxalates by oxalic acid from which the thorium oxalate is separated by means of a large excess of ammonium oxalate, precipitated by hydrochloric acid and afterwards transformed into thorium nitrate which on heating yields the oxide.

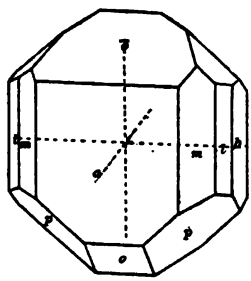
MONAZITE.

COMPOSITION. — (Ce.La.Di)PO_4, but with notable quantities of thorium and silicon and frequently small amounts of erbium and ytterbium.

GENERAL DESCRIPTION. — Small, brown, resinous crystals, or yellow, translucent grains, disseminated or as sand. Sometimes in angular masses.

CRYSTALLIZATION. — Monoclinic. Axes $\grave{a} : \bar{b} : \grave{c} = 0.969 : 1 : 0.926$; $\beta = 76° 20'$. Crystals are usually small and flat, but sometimes large. Fig. 366 shows the pinacoids *a* and *b*, the unit pyramid, prism and dome *p*, *m* and *o* and the prism $l = (2a : b : \infty c)$; $\{120\}$. Supplement angles $mm = 86° 34'$; $ab = 39° 12'$, $pp = 73° 19'$.

FIG. 366.



OPTICALLY +, with axial plane nearly *a* and acute bisectrix nearly vertical. Axial angle in red light $2E = 29°$ to $31°$.

Physical Characters. — H., 5–5.5. Sp. gr., 4.9–5.3.

LUSTRE, resinous. OPAQUE, to translucent.

STREAK, white. TENACITY, brittle.

COLOR, clove or reddish brown, yellow. CLEAVAGE, basal, perfect.

BEFORE BLOWPIPE, ETC. Turns gray when heated, but does not fuse. Is decomposed by hydrochloric acid with a white residue. Solutions added to a nitric acid solution of ammonium molybdate produce a yellow precipitate.

* *Mineral Resources*, 1902, 23.

REMARKS. — Monazite is found in considerable quantities in North and South Carolina, as sand and as a rock constituent. The Brazilian sand which is now the chief source of supply is found at Bahia, Minas Geraes, Caravellas, San Pedro and Antigua.

USES. — It is the chief source of the thoria used in mantles for incandescent gas lighting. It is also the chief source of the rare elements cerium, lanthanum and didymium.

THORITE. — Orangite.

COMPOSITION. — $ThSiO_4$, carrying some water.

GENERAL DESCRIPTION. — Black or orange-yellow tetragonal crystals like those of zircon. Also found massive.

PHYSICAL CHARACTERS. — Translucent to transparent. Lustre resinous. Color black, brown and orange. Streak, orange to brown. Brittle. H., 4.5–5. Sp. gr., 4.8–5.2.

BEFORE BLOWPIPE, ETC. — Infusible. Gelatinizes with hydrochloric acid before being heated by blowpipe but not after. In closed tube yields water and the orange variety becomes nearly black while hot, but changes to orange again on cooling.

REMARKS. — Occurs chiefly in Norway.

USES. — Is a source of thoria, but less important than monazite.

CHAPTER XXVI.

LEAD AND BISMUTH MINERALS.

THE LEAD MINERALS.

THE minerals described are:

Metal	*Lead*	Pb	Isometric
Sulphide	**Galenite**	PbS	Isometric
Sulphantimonites	*Bournonite*	$PbCuSbS_3$	Orthorhombic
	Jamesonite	$Pb_2Sb_2S_5$	Orthorhombic
Selenide	*Clausthalite*	$PbSe$	Isometric
Oxide	*Minium*	Pb_3O_4	
Sulphate	**Anglesite**	$PbSO_4$	Orthorhombic
Phosphate	**Pyromorphite**	$Pb_5Cl(PO_4)_3$	Hexagonal
Arsenate	*Mimetite*	$Pb_5Cl(AsO_4)_3$	Hexagonal
Carbonate	**Cerussite**	$PbCO_3$	Orthorhombic
Chromate	*Crocoite*	$PbCrO_4$	Monoclinic
Vanadates	**Vanadinite**	$Pb_5Cl(VO_4)_3$	Hexagonal
	Descloizite	$(Pb.Zn)(PbOH)VO_4$	Orthorhombic
Molybdate	**Wulfenite**	$PbMoO_4$	Tetragonal

The most important ores of lead are galenite and cerussite.

The world uses nearly 900,000 tons of lead per year, of which this country, in 1903, produced 289,030 tons.* Of this about one quarter was soft lead, mainly produced in Missouri and Kansas, containing almost no silver and gold. During the same year one half of the total output of lead was desilverized; indeed, it may be said that by far the most important use of lead ore is to mix and smelt with silver ores, whereby metallic lead containing silver and gold is obtained.

The principal use of metallic lead is in the manufacture of white lead, 112,700 tons being produced in 1903 in the United States alone. Large amounts are also used for the preparation of red lead, litharge, shot, lead pipe and sheet lead. A certain amount of lead containing antimony is used in type and in alloys for friction-bearings.

The argentiferous lead ores of the west, which ordinarily run low in lead are smelted in blast-furnaces. The ore, if it contains

* *Engineering and Mining Journal*, 1904, p. 4.

much sulphur, is roasted, to remove the sulphur and other volatile constituents, and is then fused, forming a silicate, which is charged in the furnace with the proper proportions of fuel and flux (limestone, hematite, etc.). The reduction takes place under the action of the blast. Metallic lead, carrying most of the silver, is produced, and if either sulphur or arsenic is present, a sulphide (matte) and an arsenide (speiss) of iron, copper, etc., will form, and above all these will float the slag composed of the gangue and the flux.

The furnace is usually oblong in section, and the hearth is connected, by a channel from the bottom, with an outer basin or well, so that the metal stands at the same level in each and can easily be ladled out. Above the hearth, and enclosing the smelting zone, are what are called the water-jackets, in which cold water circulates. The furnace gases pass through a series of condensing chambers.

The matte, speiss and the dust collected in the condensing chambers are all treated for silver, gold, lead, copper, etc., usually at different works. The metallic lead, or base bullion, is desilverized by remelting in large kettles, raising it to the melting-point of zinc, adding metallic zinc and cooling to a point between the melting-points of zinc and lead. The lighter solidified zinc separates, *carrying with it the silver and gold*, and forms a crust on the surface of the lead, from which it is skimmed.

The lead is further purified and the zinc, gold and silver separated electrolytically or by distillation.

LEAD.—Native Lead.

COMPOSITION.—Pb, with sometimes a little Sb or Ag.

GENERAL DESCRIPTION.—Usually small plates or scales or globular masses embedded in other minerals. Very rarely in octahedrons or dodecahedrons.

PHYSICAL CHARACTERS.—Opaque. Lustre metallic. Color and streak lead gray. H., 1.5. Sp. gr., 11.37. Malleable.

BEFORE BLOWPIPE, ETC.—Fuses easily, coating charcoal with yellow oxide, and tinging flame light blue. Soluble in dilute nitric acid.

GALENITE.—Galena.

COMPOSITION.—PbS (Pb 86.6 per cent.), usually with some silver and frequently sulphide of antimony, bismuth, cadmium, etc.

GENERAL DESCRIPTION.—A soft, heavy, lead-gray mineral, with metallic lustre and easy cubical cleavage. Sometimes in crystals. Rarely fine-grained or fibrous.

CRYSTALLIZATION.— Isometric. Usually the cube, Fig. 368, or cubo-octahedron, Fig. 369, sometimes octahedral or showing that

FIG. 367.

Galenite, Galena, Ill. N. Y. State Museum.

rare form the trisoctahedron $r = (a : a : 2a)$; $\{221\}$; Fig. 370. Sometimes twinned or in skeleton crystals or reticulated.

FIG. 368.

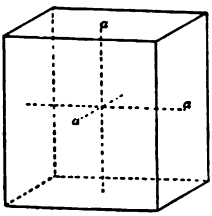


FIG. 369.

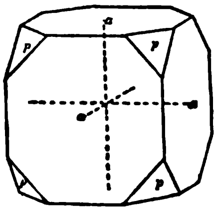
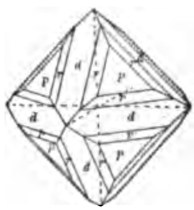


FIG. 370.



Physical Characters.—H., 2.5. Sp. gr., 7.4 to 7.6.

LUSTRE, metallic. OPAQUE.
STREAK, lead-gray. TENACITY, brittle.
COLOR, lead-gray. CLEAVAGE, cubic, very easy.

BEFORE BLOWPIPE, ETC.—On charcoal decrepitates and fuses easily, yielding in O. F. a white sulphate coat, and in R. F. a yellow coat and metallic button of lead. With bismuth flux, gives a strong iodide coat, which appears chrome-yellow on plaster and greenish-yellow on charcoal. With soda, yields malleable lead and a sul-

phur test. Soluble in excess of hot hydrochloric acid, from which white lead chloride separates on cooling. Soluble also in strong nitric acid, with separation of sulphur and lead sulphate.

SIMILAR SPECIES.—Characterized by its cleavage, weight and appearance, except in some fine-grained varieties.

REMARKS.—Galenite is the common and parent ore of lead. It occurs with other sulphides, especially sphalerite, pyrite and chalcopyrite, with a gangue of quartz, fluorite, barite or calcite. Also with ores of silver and gold. It changes easily to cerussite, anglesite and other lead minerals. Besides the silver-producing States of Colorado, Utah and Montana, which also produce the most lead, Kansas, Wisconsin and Missouri manufacture much soft lead from their deposits of galenite.

USES.—It is the chief ore of lead, and as it usually contains silver, the silver-bearing deposits are more frequently worked than the purer galenite, and both the lead and silver are recovered.

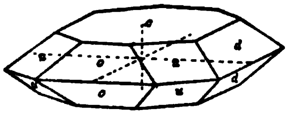
BOURNONITE.

COMPOSITION.—$PbCuSbS_3$, (Pb 42.5, Cu 13.0, Sb 24.7, S 19 8 per cent.).

GENERAL DESCRIPTION.—A gray metallic mineral, nearer steel-gray than galenite, and occurring fine-grained, massive and in thick tabular crystals. More like tetrahedrite than galenite when massive.

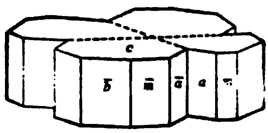
CRYSTALLIZATION.—Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c} = 0.938 : 1 : 0.897$. Common forms the pinacoids a, b, c, the unit domes and prism d, o, and m, and the pyramid $u = (\breve{a} : \bar{b} : \frac{1}{2} c)$; $\{112\}$. Short prismatic or tabular, with vertically striated faces, or, in cross, Fig. 372, and "cog-wheel" twins. Supplement angles $mm = 86° 20'$, $co = 43° 43'$; $cu = 33° 15'$.

FIG. 371.



Harz.

FIG. 372.



Kapnik.

PHYSICAL CHARACTERS. — Opaque. Lustre, metallic. Color, steel-gray to nearly black. Streak, steel-gray. H., 2.5 to 3. Sp. gr., 5 7 to 5.9. Brittle. Cleavages imperfect.

BEFORE BLOWPIPE, ETC.—On charcoal, fuses easily, yielding heavy white sublimate, and later a yellow sublimate. With bismuth flux yields strong greenish-yellow coat on charcoal and a mingling of chrome yellow and peach red on plaster. After sublimates have formed, the residue will color the flame deep green, or if moistened with a drop of hydrochloric acid, will color the flame bright azure blue. Soluble in nitric acid to a green solution, with formation of a white insoluble residue.

JAMESONITE.—Feather Ore.

COMPOSITION.—$Pb_2Sb_2S_5$. (Pb 50.8, Sb 29.5, S 19.7 per cent.).

GENERAL DESCRIPTION.—Steel-gray to dark-gray metallic needle crystals, or hair-like and felted; also compact and fibrous massive.

PHYSICAL CHARACTERS —Opaque. Lustre, metallic. Color, steel-gray to dark-lead gray. Streak, grayish-black. H., 2 to 3; Sp. gr., 5.5 to 6. Brittle.

BEFORE BLOWPIPE, ETC.—Decrepitates and fuses very easily, and is volatilized, coating the charcoal white and yellow as in bournonite. With bismuth flux, reacts like bournonite. In closed tube, yields dark-red sublimate, nearly black while hot. Soluble in hot hydrochloric acid, with effervescence of hydrogen sulphide.

CLAUSTHALITE.

COMPOSITION.—PbSe, (Pb 72.4, Se 27.6 per cent.). May contain silver or cobalt.

GENERAL DESCRIPTION.—Bluish gray fine granular masses of metallic lustre. Rarely foliated. Resembles galenite.

PHYSICAL CHARACTERS.—Opaque. Lustre, metallic. Color, bluish lead gray Streak, grayish black. H., 2.5 to 3. Sp. gr., 7.6 to 8.8.

BEFORE BLOWPIPE, ETC.—On charcoal fuses and yields odor like decayed horse-radish, coats the charcoal with a white sublimate with red border, and later a yellow coat forms. In open tube gives a red sublimate. With soda yields a mass which blackens silver.

MINIUM.

COMPOSITION.—Pb_3O_4, (Pb 90.6 per cent.).

GENERAL DESCRIPTION.—A vivid red powder or loosely compacted mass of dull or greasy lustre. Often intermixed with yellow.

PHYSICAL CHARACTERS.—Opaque. Bright red. Lustre, dull or greasy. Streak, orange yellow. H., 2 to 3. Sp. gr., 4.6.

BEFORE BLOWPIPE, ETC.—Is reduced to metallic lead, and yields the characteristic lead sublimates.

REMARKS. —The artificial product is the red lead of commerce.

ANGLESITE.

COMPOSITION.—$PbSO_4$, (PbO 73.6, SO_3 26.4 per cent.).

GENERAL DESCRIPTION.—A very brittle, colorless or white mineral of adamantine lustre, sometimes colored by impurities. Usually massive, frequently in concentric layers around a core of unaltered galenite.

FIG. 373.

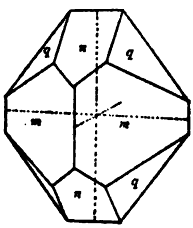
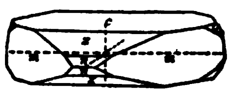


FIG. 374.



Phœnixville, Pa.

CRYSTALLIZATION.—Orthorhombic. Axes $\breve{a} : \bar{b} : c = 0.785 : 1 : 1.289$. Crystals vary greatly in type, but are rarely twinned. Unit prism m and domes such as $n = (a : \infty b : \frac{1}{2}c)$; $\{102\}$; $z = (a : \infty b : \frac{1}{4}c)$; $\{104\}$; and pyramids $q = (2a : b : c)$; $\{122\}$ are frequent.

Supplement angles: $mm = 76° \ 17'$; $cn = 33° \ 24'$; $cz = 22° \ 19'$; $cq = 56° \ 48'$.

Optically +, with high indices of refraction 1.877, 1.882 and 1.893 for yellow light. Axial plane is the brachy pinacoid b.

Physical Characters. H., 3. Sp. gr., 6.12 to 6.39.

LUSTRE, adamantine to vitreous. TRANSPARENT to opaque.
STREAK, white. TENACITY, very brittle.
COLOR, colorless, white, gray; rarely yellow, blue or green.
CLEAVAGE, basal and prismatic (90° and 103° 43′).

BEFORE BLOWPIPE, ETC.—On charcoal decrepitates and fuses easily to a glassy globule pearly white on cooling. In R. F. is reduced and yields metallic lead and the yellow sublimate. With soda yields the sulphur reaction. Insoluble in hydrochloric acid but is converted into chloride. Slowly soluble in nitric acid.

SIMILAR SPECIES.—It differs from the carbonate, cerussite, in absence of twinned crystals and of effervescence in acids. It is heavier than barite and celestite, and yields lead.

REMARKS.—Anglesite is formed by the oxidation of galenite. It alters to the carbonate, cerussite, by interchange with calcium carbonate in solution. It is found throughout the United States wherever exposed deposits of galenite occur. The lead mines of Missouri, Wisconsin, Colorado, etc., all contain this mineral. It occurs in large quantities in Mexico and Australia.

USES.—It is an ore of lead.

Linarite.—$[(PbCu)OH]_2SO_4$. In small, deep blue, monoclinic crystals.

PYROMORPHITE.

COMPOSITION.—$Pb_5Cl(PO_4)_3$, (PbO 82.2, P_2O_5 15.7, Cl 2.6 per cent.) often with some As, Fe or Ca.

GENERAL DESCRIPTION.—Short hexagonal prisms and branching and tapering groups of prisms in parallel position. The color is most frequently green, brown, or gray. Also in moss-like interlaced fibers and masses of imperfectly developed crystals. Less frequently in globular and reniform masses.

CRYSTALLIZATION. — Hexagonal, class of third order pyramid p. 51.

Axis $c = 0.736$. Usual form prism m and base c. Faces m horizontally striated, sometimes tapering.

FIG. 375.

Pyromorphite, Ems, Germany. N. Y. State Museum.

Physical Characters. H., 3.5 to 4. Sp. gr., 5.9 to 7.1.

LUSTRE, resinous. TRANSLUCENT to opaque.

STREAK, white to pale yellow. TENACITY, brittle.

COLOR, green, gray, brown; also yellow, orange, white.

BEFORE BLOWPIPE, ETC.—On charcoal fuses to a globule which on cooling does not retain its globular form but crystallizes, showing plane faces. In reducing flame yields white coat at a distance and yellow coat nearer the assay, and a brittle globuie of lead. In closed tube with magnesium ribbon yields a phosphide which, moistened with water, evolves phosphine. With salt of phosphorus saturated with copper oxide yields an azure blue flame. Soluble in nitric acid, and from the solution ammonium molybdate throws down a yellow precipitate.

SIMILAR SPECIES.—Differs from other lead minerals in fusing to a crystalline globule without reduction.

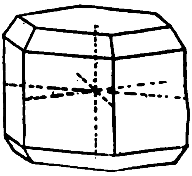
REMARKS—Probably formed from galenite. Occurs with other lead minerals. Found at Phœnixville, Pa., Davidson county, N. C., Lenox, Me., and many other localities.

MIMETITE.

COMPOSITION.—$3Pb_3(AsO_4)_2 + PbCl_2$ or $Pb_5Cl(AsO_4)_3$, (PbO 74.9, As_2O_5 23.2, Cl 2.39 per cent.), often with some replacement by P or Ca.

GENERAL DESCRIPTION.—Pale yellow to brown hexagonal prisms or globular groups of crystals. Sometimes incrusting.

FIG. 376.



PHYSICAL CHARACTERS.—Translucent. Lustre, resinous. Color, yellow, brown or white. Streak, white. H., 3.5. Sp. Gr., 7.0 to 7.25, lower when Ca is present.

BEFORE BLOWPIPE, ETC.—On charcoal fuses easily and is reduced to metallic lead, coating the coal with white and yellow sublimates and yielding strong arsenical odor. Phosphorus, if present, and chlorine may be detected as in pyromorphite.

CERUSSITE.—White Lead Ore.

COMPOSITION.—$PbCO_3$, (PbO, 83.5; CO_2, 16.5 per cent.). Often carries silver.

GENERAL DESCRIPTION.—Very brittle, white or colorless orthorhombic crystals; silky, milk-white masses of interlaced fibres; granular, translucent, gray masses and compact or earthy, opaque masses of yellow, brown, etc., colors.

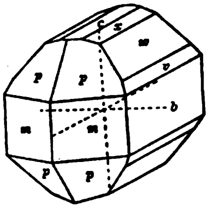
FIG. 377.

Cerussite, Arizona. N. Y. State Museum.

CRYSTALLIZATION.—Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c} = 0.610 : 1 : 0.723$. Common forms: unit pyramid p, and prism m and a series of brachy domes such as $x = (\infty \breve{a} : \bar{b} : \frac{1}{2}c)$; $\{012\}$; $w = (\infty \breve{a} : \bar{b} : 2c)$; $\{021\}$ and $v = (\infty \breve{a} : \bar{b} : 3c)$; $\{031\}$. Frequently twinned

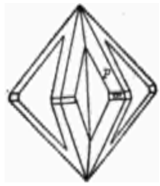
about *m* sometimes yielding six-rayed groups as in Fig. 379. Supplement angles are $mm = 62° 46'$, $pp = 50°$, $ww = 110° 40'$.

FIG. 378.



Black Hawk, Mont.

FIG. 379.



Transbaikal.

Optically —. Axial plane *b*. Acute bisectrix normal to *c*. High indices of refraction : 1.804, 2.076, 2.078 in yellow light.

Physical Characters. — H., 3 to 3.5. Sp. gr., 6.46 to 6.51.

LUSTRE, adamantine, silky. TRANSPARENT or translucent.
STREAK, white. TENACITY, very brittle.
COLOR, white, gray, colorless or colored by impurities.
CLEAVAGES, parallel to prism and brachy dome.

BEFORE BLOWPIPE, ETC.—On charcoal, decrepitates, fuses and gives a yellow coating, and finally a metallic globule. In closed tube, turns yellow, then dark, and on cooling is yellow. Effervesces in acids, but with hydrochloric or sulphuric acid leaves a white residue.

SIMILAR SPECIES.—Distinguished from anglesite by effervescence in acids and by frequent occurrence of twinned crystals. Has higher specific gravity than most carbonates.

REMARKS.—Cerussite is derived from galenite by the action of water containing carbon dioxide. It may also be produced from anglesite by action of a solution of calcium carbonate.

USES.—It is smelted for lead and silver, and a process exists for the direct manufacture of white lead from cerussite.

Phosgenite. — $Pb_2C_2CO_3$. In transparent, colorless or gray tetragonal crystals.

CROCOITE.

COMPOSITION.—$PbCrO_4$, (PbO, 68.9; CrO_3, 31.1 per cent.).

GENERAL DESCRIPTION.—Bright hyacinth-red mineral, usually in monoclinic prismatic crystals, but also granular and columnar. The color is like that of potassium dichromate.

PHYSICAL CHARACTERS.—Translucent. Lustre, adamantine. Color, hyacinth red. Streak, orange yellow. H., 2.5 to 3. Sp. gr., 5.9 to 6.1. Sectile. Cleavage, prismatic.

BEFORE BLOWPIPE, ETC.—In closed tube, decrepitates violently, becomes dark, but recovers color on cooling. Fuses very easily, and is reduced to metallic lead with deflagration, the coal being coated with a yellow sublimate. With borax or S.Ph., forms yellow glasses, which are bright green when cold. Soluble in nitric acid to a yellow solution. Fused with $KHSO_4$ in closed tube, yields a dark-violet mass, red on solidifying and greenish-white when cold, which distinguishes it from vanadinite.

VANADINITE.

COMPOSITION.—$3Pb_3(VO_4)_2 \cdot PbCl_2$ or $Pb_5Cl(VO_4)_3$, (PbO, 78.7; V_2O_5, 19.4; Cl, 2.5 per cent.), often with P or As replacing V.

FIG. 381.

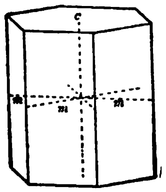
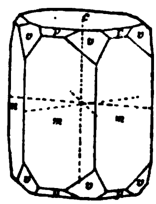


FIG. 382.



GENERAL DESCRIPTION. — Small, sharp, hexagonal prisms, sometimes hollow, of bright-red, yellow or brown color. Also parallel groups and globular masses of crystals.

CRYSTALLIZATION. — Hexagonal. Class third order pyramid, p. 51. Axis $c = 0.712$. Simple prism m with base c, or more rarely with pyramid p and third order pyramid $v = (\frac{3}{2}a : 3a : a : 3c)$; $\{2131\}$, Fig. 382.

Physical Characters. — H., 3. Sp. Gr., 6.66 to 7.23.

LUSTRE, resinous on fracture. OPAQUE, or translucent.

STREAK, white to pale yellow. TENACITY, brittle.

COLOR, deep red, bright red, yellow or brown.

BEFORE BLOWPIPE, ETC.—Fuses easily on charcoal to a black mass, yielding a yellow sublimate in the reducing flame. The residue gives deep-green bead, with salt of phosphorus in the reducing flame. With strong nitric acid the substance becomes deep red, then dissolves to a yellow solution. Fused with $KHSO_4$, yields a clear yellow, then a red, and finally yellow when cold.

USES.—It is the source of vanadium, for vanadium black; for

vanadium salts, which are used as a mordant in the manufacture of the finest silks; for vanadium bronze and for vanadium ink.

DESCLOIZITE.

COMPOSITION. — $(Pb.Zn)(PbOH),VO_4$. (PbO, 55.4; ZnO, 19.7; V_2O_5, 22.7; H_2O, 2.2).

GENERAL DESCRIPTION.—Small purplish-red, brown or black crystals, forming a drusy surface or crust. Also fibrous, massive.

PHYSICAL CHARACTERS.—Transparent to nearly opaque. Lustre, greasy. Color, purplish red, brown or black. Streak, orange or brown. H., 3.5. Sp. gr., 5.9 to 6.2.

BEFORE BLOWPIPE, ETC.—On charcoal, fuses to black mass, enclosing metal. In closed tube yields water. Vanadium reactions as in vanadinite.

WULFENITE.

COMPOSITION.—$PbMoO_4$, sometimes containing Ca, Cr. V.

GENERAL DESCRIPTION.—Usually in thin, square, tabular crystals of yellow, orange or bright orange-red color and resinous lustre. Less frequently in granular masses or acute pyramidal crystals.

FIG. 383.

Wulfenite, Red Cloud Mine, Arizona. Foote Mineral Co.

CRYSTALLIZATION. — Tetragonal. Class of third order pyramid, p. 41. Axis $c = 1.577$. Usually the base c with the pyramid

FIG. 384.

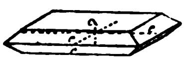


FIG. 385.

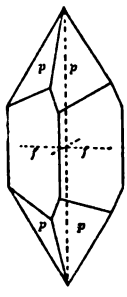
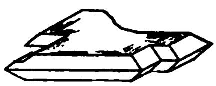


FIG. 386.



$e = (a : \infty a : \frac{1}{2}c)$; $\{102\}$. More rarely the unit pyramid p and a third order prism $f = (a : \frac{3}{2}a : \infty c)$; $\{320\}$. Angle $ce = 38° 15'$, $pp = 80° 22'$.

Optically —.

Physical Characters. H., 3. Sp. gr., 6.7 to 7.

LUSTRE, resinous or adamantine. TRANSLUCENT.
STREAK, white. TENACITY, brittle.
COLOR, wax yellow, bright red, brown, rarely green.
CLEAVAGE, pyramidal.

BEFORE BLOWPIPE, ETC.—Fuses easily on charcoal, giving yellow coat and finally a metallic globule. In salt of phosphorus dissolves to a bead, which is bright green in R. F. In borax, yields a colorless bead in O. F., which is made brown to black in R. F. Partially soluble in strong hydrochloric acid to a green liquid. If the solution is greatly diluted, *cooled* and tin added, it becomes deep blue and finally brown. A similar test may be obtained either by boiling in porcelain with strong sulphuric acid and adding alcohol, or by fusing in platinum with $KHSO_4$, dissolving in water and boiling with tin or zinc.

REMARKS.—Wulfenite occurs with other lead minerals, especially vanadinite and pyromorphite. It is found in many localities in New Mexico and Arizona; in the lead regions of Wisconsin and Missouri; at Phœnixville, Pa.; Inyo County, Cal.; Southampton, Mass., and many other places, always associated with other ores of lead.

THE BISMUTH MINERALS.

The minerals described are:

Metal	**Bismuth**	Bi	Hexagonal
Sulphide	*Bismuthinite*	Bi_2S_3	Orthorhombic
Telluride	*Tetradymite*	$Bi_2(Te.S)_3$	Hexagonal
Carbonate	*Bismutite*	$(BiO)_2CO_3.H_2O$	
Oxide	*Bismite*	Bi_2O_3	Orthorhombic

Bismuth is also found intimately mixed with other minerals, as with tin ore in Bolivia; cobalt ore in Saxony and gold-bearing magnetite in Queensland, Australia.

The principal source of bismuth is the native metal; it is, however, extracted from the other minerals, and to a considerable extent from the hearths and last products of oxidation of lead cupellation. The manufacture is practically all in Germany and England, the latter country reducing Australian and Bolivian ores. The quantity produced per year is small.

The uses of bismuth are chiefly dependent upon its property of forming easily fusible alloys with other metals, especially tin, lead, and cadmium. These alloys expand in cooling, and are therefore used in reproducing woodcuts, in making safety plugs for boilers, etc. The salts of bismuth have numerous uses in medicine and in the arts, are used in calico printing, cosmetics, and in making glass of high refractive power, and also to impart lustre to porcelain.

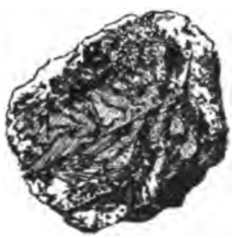
Bismuth was formerly obtained from the native metal by simply heating in a closed, inclined vessel, the liquid metal flowing out. This method was wasteful, as any bismuth present as sulphide or telluride was not obtained while much of the metal was lost. In Saxony where most of the bismuth of the world is produced the ores are first roasted to free them from sulphur, arsenic and other volatile constituents. After roasting they are smelted in crucibles with iron, charcoal and slag, the melted bismuth settling out in the bottom of the crucible; or the roasted ores may be treated with strong hydrochloric acid (1 : 1) which dissolves the bismuth and from which it is precipitated as oxychloride by the addition of water. The metal may be further purified electrolytically. When bismuth is found to be present in the cupellation of lead ore, it is recovered by saving the last products of oxidation and the hearth of the furnace, grinding these and treating them with hot strong hydrochloric acid. After settling and cooling the liquid is siphoned off and diluted with water, by which a precipitate of the oxychloride is produced, which, after being dissolved in hydrochloric acid and reprecipitated some two or three times to separate lead chloride, is easily reduced to metallic bismuth by fusion with soda, or lime, charcoal and a silicious slag.

BISMUTH.—Native Bismuth.

COMPOSITION. — Bi, often alloyed with As or impure from S or Te.

GENERAL DESCRIPTION. — A brittle silver-white mineral with a reddish tinge, usually disseminated through the gangue in branching lines, Fig. 387, or in isolated grains or lumps. Rarely in indistinct hexagonal crystals.

FIG. 387.



Schneeberg, Saxony.

Physical Characters. H., 2 to 2.5. Sp. gr., 9.7 to 9.83.

LUSTRE, metallic. OPAQUE.

STREAK, silver white. TENACITY, sectile to brittle.

COLOR, reddish silver white.

BEFORE BLOWPIPE, ETC.—On charcoal fuses easily and volatilizes completely, coating the charcoal with a yellow sublimate. With bismuth flux forms a chocolate brown and red coating which is best seen on plaster, and which is changed by action of ammonia fumes to red and orange. Soluble in strong nitric acid from which solution water will precipitate a white basic salt.

SIMILAR SPECIES.—Bismuth is characterized by its silver streak, reddish tinge, and arborescent structure.

REMARKS.—Bismuth occurs in crystalline rocks and clay slate associated with ores of cobalt, nickel, silver, gold, lead and zinc, also with molybdenite, wolframite, scheelite. The native metal is not found in any quantity in the United States, although obtained at Monroe, Ct., n Colorado, and in South Carolina. The most celebrated foreign localities are Schneeberg in Saxony and other places both in Saxony and Bohemia. Found also at Copiapo, Chili; in Bolivia, Sweden, Norway, and in South Australia.

USES.—It is a source of commercial bismuth and of salts of bismuth.

BISMUTHINITE.

COMPOSITION.—Bi_2S_3, (Bi 81.2, S 18.8 per cent.). May contain Cu or Fe.

GENERAL DESCRIPTION.—A lead gray mineral of metallic lustre usually occurring in foliated or fibrous masses, or in groups of long needle-like orthorhombic crystals.

PHYSICAL CHARACTERS.—Opaque. Lustre, metallic. Color, lead gray or lighter, often with yellow tarnish. Streak, lead gray. H., 2. Sp. gr., 6.4 to 6.5. Slightly sectile.

BEFORE BLOWPIPE, ETC.—On charcoal yields some sulphur, fuses easily with spirting, and coats the coal with white and yellow sublimates. Yields the characteristic bismuth reactions with bismuth flux and with nitric acid as described under bismuth. With soda gives sulphur reaction.

Aikinite. — $BiPbCuS_3$. Needles of dark gray color embedded in quartz.

TETRADYMITE.

COMPOSITION.—$Bi_2(Te.S)_3$ or BiTeS. Either an alloy or a telluride of bismuth.

GENERAL DESCRIPTION.—Very soft, flexible, foliated masses of steel-gray color and bright metallic lustre, or small indistinct rhombohedral crystals. Will mark paper like graphite.

PHYSICAL CHARACTERS, ETC.—Opaque. Lustre, metallic. Color, pale steel-gray, Streak, gray. H., 1.5 to 2. Sp. gr., 7.2 to 7.6. Flexible in laminæ. Cleavage, basal.

BEFORE BLOWPIPE, ETC.—On charcoal fuses easily and is completely volatilized, yielding a white fusible sublimate, followed by a yellow sublimate. The flame during fusion is colored blue. The white sublimate if placed on procelain and moistened with concentrated sulphuric acid becomes rose colored. If dropped into boiling concentrated sulphuric acid a deep violet color is produced.

BISMUTITE.

COMPOSITION. — $(BiO)_2CO_3$, H_2O, variable.

GENERAL DESCRIPTION. — A light colored incrustation or earthy mass or powder.

PHYSICAL CHARACTERS. — Opaque. Lustre, dull or vitreous. Color, white, green and yellow. Streak, colorless to greenish. H., 4-4.5; Sp. gr., 6.9-7.7. Tenacity, brittle.

BEFORE BLOWPIPE, ETC. — Fuses easily on charcoal, giving a yellow coat and in R. F. a metallic globule which completely volatilizes. With bismuth flux on plaster gives brown and red coat. Yields water in closed tube and decrepitates. Soluble with effervescence in strong HCl, and on dilution with much water the white oxychloride of bismuth is precipitated.

USES. — Is an important ore of bismuth.

REMARKS. — It is usually associated with metallic bismuth or the sulphide and occurs at Brewer' Mine, S. C., Phœnix, Arizona, Inyo Co., Cal.

BISMITE. — Bismuth Ochre.

COMPOSITION. — Bi_2O_3, Bi 89.6 per cent. when pure.

GENERAL DESCRIPTION. — A yellowish or gray powder or earthy mass.

PHYSICAL CHARACTERS. — Opaque. Color, grayish, greenish or yellowish white. Lustre, dull.

BEFORE BLOWPIPE, ETC. — As for bismutite but does not effervesce with acids nor yield water in closed tube.

USES. — It is the source of some bismuth.

CHAPTER XXVII.

ARSENIC, ANTIMONY, URANIUM AND MOLYBDENUM MINERALS.

THE ARSENIC MINERALS.

THE minerals described are:

Metal	*Arsenic*	As	Hexagonal
Sulphides	**Orpiment**	As_2S_3	Orthorhombic
	Realgar	As_2S_2	Monoclinic

The principal sources of metallic arsenic and white arsenic are not the above mentioned minerals, but the arsenides and arseno-sulphides of iron, cobalt and copper. The greater part of the world's supply of arsenic and its compounds comes from Cornwall, England; Freiberg, Saxony; and from Prussia.

Metallic arsenic is ordinarily produced by sublimation from a mixture of the oxide and charcoal, but may be produced by sublimation at a high heat directly from arsenopyrite out of contact with air. It is a constituent of some useful alloys, shot metal being the chief.

The poisonous oxide commonly known as arsenic or white arsenic, is produced in large quantities by the roasting of arsenopyrite and other arsenical ores and as a by-product in the preparation of tin, silver, nickel and cobalt. It is used in dyeing, in medicine, in sheep washing, in calico printing, as a preservative for timber and for natural history specimens, in the manufacture of fly paper, and rat poisons, and in glass manufacture. Many important coloring matters as well as the artificial red and yellow sulphides are commercial products. Paris green is an arsenate of copper extensively used as an insecticide. The production of arsenic in 1903 in the United States was 590 tons.*

ARSENIC.—Native Arsenic.

COMPOSITION.—As, generally with some Sb and sometimes with Bi or a little Co, Ni, Fe, Ag or Au.

* *Eng. and Min. Jour.*, 1904, p. 4.

GENERAL DESCRIPTION.—A tin-white metal, tarnishing almost black. Usually granular, massive, with reniform surfaces. Can frequently be separated in concentric layers. Rarely found in needle-like crystals.

PHYSICAL CHARACTERS.—Opaque. Lustre, nearly metallic. Color, tin white, tarnishing nearly black. Streak, tin white. H., 3.5. Sp. gr., 5.63 to 5.73. Brittle. Granular fracture.

BEFORE BLOWPIPE, ETC.—On charcoal, volatilizes without fusion, yielding strong garlic odor, white fumes, crystalline white sublimate and pale blue flame. May leave a residue of impurities.

REALGAR.

COMPOSITION.—As_2S_2, (As, 70,1 ; S, 29.9 per cent.).

GENERAL DESCRIPTION.—A soft, orange-red mineral, of resinous lustre, usually occurring in translucent, granular masses, but also compact and in transparent monoclinic crystals.

Physical Characters. H., 1.5 to 2. Sp. gr., 3.4 to 3.6.

LUSTRE, resinous.	TRANSLUCENT to transparent.
STREAK, orange red.	TENACITY, slightly sectile.

COLOR, aurora red, becoming orange yellow on long exposure.

BEFORE BLOWPIPE, ETC.—On charcoal, fuses easily, burns with a blue flame, yields white fumes, with garlic odor and also odor of sulphur dioxide and is volatilized completely. In closed tube yields red sublimate. Soluble in nitric acid, with separation of sulphur. Soluble also in potassium hydroxide from which hyd ochloric acid precipitates yellow flakes.

REMARKS.—Realgar is found with orpiment, arsenolite, galenite, argentite, etc., and is formed both by sublimation and by deposition from water. Realgar is obtained mainly from abroad, notably from Hungary and the island of Borneo. Deposits are known in Utah, California and Wyoming.

USES.—The artificial sublimate is used in fireworks and for signalling, in the form of "white Indian fire." It also is used as a pigment.

ORPIMENT.

COMPOSITION.—As_2S_3, (As, 61 ; S, 39 per cent.).

GENERAL DESCRIPTION.—Lemon-yellow, foliated masses, which cleave into thin, pearly, flexible scales, and also granular masses like yolk of hard-boiled eggs. Less frequently as reniform crusts and imperfect orthorhombic crystals.

Physical Characters. H., 1.5 to 2 Sp. gr., 3.4 to 3.6.

LUSTRE, resinous or pearly. TRANSLUCENT to nearly opaque.
STREAK, lemon yellow. TENACITY, slightly sectile.
COLOR, lemon yellow. CLEAVAGE, in plates or leaves.

BEFORE BLOWPIPE, ETC.—As for realgar, except that the sublimate in closed tube is yellow.

REMARKS.—Probably generally formed by sublimation, but is also deposited from hot water, and formed by alteration of realgar in air and sunlight. It occurs with realgar, arsenic, arsenolite, etc. Obtained mainly from several Hungarian localities, from Borneo, and from Kurdistan, Turkey. Found in powder at Edenville, N. Y., and massive in Wyoming, Utah and Nevada.

USES.—The artificial material is used in dyeing to reduce indigo, and in tanning, as a constituent with potash and lime, to remove hair from the skins and as a pigment.

THE ANTIMONY MINERALS.

The minerals described are:

Metal	*Antimony*	Sb	Hexagonal
Sulphides	**Stibnite**	Sb_2S_3	Orthorhombic
	Kermesite	Sb_2S_2O	Monoclinic
Oxide	*Valentinite*	Sb_2O_3	Orthorhombic

Lead ores also frequently contain antimony.

The only commercially important antimony mineral is the sulphide, a little of which is used as sulphide in vulcanizing rubber, and in safety matches, percussion caps, fireworks, etc., but is chiefly important as a source of the metal. In 1903 this country produced 3,400 tons * of metallic antimony, and used about twice that quantity, chiefly in preparing type and stereotype metal and other alloys. Type metal is now, however, principally produced from antimonial lead obtained as a by-product in refining base bullion.

France, Italy, Mexico and Japan are at present the chief producers.

In smelting, the ore is heated and the melted sulphide drained off. The sulphide may then be roasted, forming the oxide, which is easily reduced by fusion with charcoal, or more frequently the sulphide is mixed with wrought-iron scraps and salt, placed in a

* *Eng. and Min. Jour.*, 1904, p. 3.

crucible or furnace and fused. The iron combines with the sulphur and the metallic antimony settles to the bottom.

The metal produced by either method is usually refined by smelting with sodium carbonate and a little antimony sulphide, followed by two fusions with sodium carbonate alone.

ANTIMONY.—Native Antimony.

COMPOSITION.—Sb, sometimes with As, Fe or Ag.

GENERAL DESCRIPTION.—A very brittle, tin white metal, usually massive, with fine, granular, steel-like texture or lamellar or radiated. Very rarely in rhombohedral crystals or complex groups.

PHYSICAL CHARACTERS.—Opaque. Lustre, metallic. Color, tin white. Streak tin white. H., 3 to 3.5. Sp. gr., 6.5 to 6.72. Very brittle.

BEFORE BLOWPIPE, ETC.—Fuses very easily, colors the flame pale green, gives copious white fumes, which continue to form as a thick cloud after cessation of blast, and often yield a crust of needle-like crystals.

STIBNITE.—Gray Antimony.

COMPOSITION.—Sb_2S_3, (Sb 71.8, S 28.2 per cent.). Sometimes contains silver or gold.

GENERAL DESCRIPTION.—A lead-gray mineral of bright metallic lustre, occurring in imperfectly crystallized masses, with columnar or bladed structure; less frequently in distinct, prismatic, orthorhombic crystals or confusedly interlaced bunches of needle-like crystals; also in granular to compact masses.

FIG. 388.

Stibnite, Felsobanya, Hungary. Columbia University.

CRYSTALLIZATION. — Orthorhombic. Axes $\breve{a} : \bar{b} : c = 0.993 : 1 : 1.018$. Prismatic forms, often bent and curved or in divergent groups. The vertical planes are striated longitudinally.

Common forms : unit prism m, unit pyramid p and pyramid $s = (\breve{a} : \bar{b} : \frac{1}{3}c)$; $\{113\}$. Supplement angles $mm = 89° 34'$; $pp = 70° 48'$; $ss = 35° 36'$.

Physical Characters. H., 2. Sp. gr, 4.52 to 4.62.

LUSTRE, metallic. OPAQUE.

STREAK, lead gray. TENACITY, brittle to sectile.

COLOR, lead gray, often with black or iridescent tarnish.

CLEAVAGE, easy, parallel to brachy pinacoid, yielding slightly flexible, blade-like strips.

BEFORE BLOWPIPE, ETC.—On charcoal, fuses very easily, yielding the same dense sublimate as antimony. The odor of sulphur dioxide may also be noticed. On charcoal, with soda, yields sulphur test. In closed tube fuses easily, yields a little sulphur and a dark sublimate which is brownish red when cold.

Soluble completely in strong boiling hydrochloric acid, with evolution of H_2S, with precipitation of white basic salt on addition of water and after dilution an orange precipitate on addition of H_2S. Strong nitric acid decomposes stibnite into white Sb_2O_5 and S. Strong hot solution of KOH colors stibnite yellow and partially dissolves it. From the solution hydrochloric acid will throw down an orange precipitate.

SIMILAR SPECIES.—Differs from galenite in cleavage, and from all sulphides by ease of fusion and cloud-like fumes.

REMARKS.—Stibnite occurs in veins with other antimony minerals formed from it, also with cinnabar, sphalerite, siderite, etc. Large deposits of stibnite occur at Lovelocks, Bernier and Austin, Nevada; at Kingston, Idaho; at San Emidio, California; in Arkansas, in Utah, in Nova Scotia and in New South Wales. The most celebrated deposit, however, is that in Shikoku, Japan, from which the very finest crystals and groups are obtained.

USES.—It is the chief source of antimony and its artificial pigment and pharmaceutical preparations. In the natural state it is used in safety matches and percussion caps, in fireworks and in rubber goods.

KERMESITE.—Red Antimony.

COMPOSITION.—Sb_2S_2O or $2Sb_2S_3 \cdot Sb_2O_3$, (Sb 75.0, S 20.0, O 5.0 per cent.).

GENERAL DESCRIPTION.—Fine hair-like tufts of radiating fibers and needle-like crystals, of a deep cherry-red color and almost metallic lustre.

PHYSICAL CHARACTERS.—Nearly opaque. Lustre, adamantine. Color, dark cherry red. Streak, brownish red. H., 1 to 1.5. Sp. gr., 4.5 to 4.6. Sectile and in thin leaves slightly flexible.

BEFORE BLOWPIPE, ETC.—As for stibnite.

REMARKS.—Kermesite results from partial oxidation of stibnite. Extensive deposits exist at Pereta, Tuscany.

VALENTINITE.

COMPOSITION. — Sb_2O_3, (Sb, 83.3 per cent.).

GENERAL DESCRIPTION. — Small white flat crystals (orthorhombic) or radiating groups of silky lustre and white or gray color. Also in spheroidal masses with radiated lamellar structure.

PHYSICAL CHARACTERS. — Translucent. Lustre, adamantine or silky. Color, white, gray, pale red. Streak, white. H., 2.5 to 3. Sp. gr., 5.57.

BEFORE BLOWPIPE, ETC. — Fuses easily, coating the charcoal with white oxide. In R. F. is reduced, but again oxidizes and coats the coal, coloring the flame green. Soluble in hydrochloric acid.

REMARKS. — Formed by oxidation and decomposition of stibnite and other ores of antimony.

Senarmontite. — Sb_2O_3. In pearl colored isometric octahedra.

THE URANIUM MINERALS.

The minerals described are:

Uranate	**Uraninite**	**Uranyl uranate**	Isometric
Vanadate	*Carnotite*	*Uranyl vanadate*	
Phosphates	*Autunite*	$Ca(UO_2)_2(PO_4)_2 \cdot 8H_2O$	Orthorhombic
	Torbernite	$Cu(UO_2)_2(PO_4)_2 \cdot 8H_2O$	Tetragonal

The metal uranium has a limited use in uranium steel, as a small percentage of uranium increases the elasticity and hardness of ordinary steel. In 1901 the United States produced 375 tons * of uranium ore.

A few tons of sodium uranate, commercially known as uranium yellow, are used each year in coloring glass yellow with a greenish reflex, and in coloring porcelain orange or black. A small amount is used in photography and in the manufacture of uranium salts important in the laboratory.

Recently an unusual interest has been developed in uranium minerals from the discovery of the new radioactive element radium in uraninite. It has also been proved to be present in many other

* *Mineral Industry*, XI., 1902, 558.

uranium minerals and is probably present in all. Many tons of uraninite have been worked over to obtain a few grams of impure radium chloride, the remarkable properties of which are being widely studied. It seems probable that there is here the first known instance of the decomposition of the chemical atom, for radium gives off helium apparently as a decomposition product, and with the evolution of an amount of energy far beyond any previous conception. It also is continually throwing off emanations or rays which affect a photographic plate and discharge an electroscope. Some of these too are of a material character. Still years must elapse before any loss of weight can be detected by the most delicate balance. Uranium minerals in general are radioactive undoubtedly from the radium they contain.

URANINITE.—Pitch Blende.

COMPOSITION.—A uranate of UO_2, Pb, etc., and may contain Ca, N, Th, Zr, Fe, Cu, Bi, etc.

GENERAL DESCRIPTION.—A black massive mineral of botryoidal or granular structure and pitch-like appearance. Rarely in small isometric crystals.

Physical Characters. H., 5.5. Sp. gr., 5 to 9.7.

LUSTRE, pitch-like, submetallic.	OPAQUE.
STREAK, gray, olive green, dark brown.	TENACITY, brittle.
COLOR, some shade of black.	

BEFORE BLOWPIPE, ETC.—Infusible or very slightly fused on edges, sometimes coloring the flame green from copper. On charcoal with soda may yield reaction for lead, arsenic and sulphur. In borax yields a green bead made enamel black by flaming. Soluble in nitric acid to a yellow liquid from which ammonia throws down a bright yellow precipitate.

SIMILAR SPECIES.—The appearance and streak are frequently sufficient distinctions. The bead tests are characteristic.

REMARKS.—Uraninite occurs both in granitic rocks and in metallic veins. It is frequently associated with minerals resulting from its decomposition and with metallic ores. It is mined at Joachimstal, Bohemia, from whence the principal supply is obtained. It occurs in Jefferson and Gilpin counties, Colorado, having been mined at Central City and is found also in some quantity in Mitchell county, N. C., at Marietta, S. C., in Texas, and in the Black Hills of South Dakota.

USES.—Uraninite is the chief source of the uranium salts used in painting on porcelain and in the manufacture of a fluorescent glass of yellowish-green color. It is the source from which all the radium chloride and bromide so far produced has been obtained.

Carnotite. — An impure uranyl vanadate occurring as a canary yellow, ocherous material in Colorado. It contains a high percentage of uranium and is a possible source of radium.

AUTUNITE—Lime Uranite.

COMPOSITION.—$Ca(UO_2)_2(PO_4)_2 + 8H_2O$, ($UO_3$ 62.7, CaO 6.1, P_2O_5 15.5, H_2O 15.7 per cent.).

GENERAL DESCRIPTION.—Nearly square (90° 43′) orthorhombic plates of bright yellow color and pearly lustre, or in micaceous aggregates.

PHYSICAL CHARACTERS.—Translucent. Lustre, pearly on base. Color, lemon to sulphur yellow. Streak, pale yellow. H., 2 to 2.5. Sp. gr., 3.05 to 3.19. Brittle. Cleavage basal.

BEFORE BLOWPIPE, ETC.—On charcoal fuses with intumescence to a black crystalline globule. With salt of phosphorus or borax in the reducing flame yields a green bead. Dissolves in nitric acid to a yellow solution.

TORBERNITE.—Copper Uranite.

COMPOSITION.—$Cu(UO_2)_2(PO_4)_2 + 8H_2O$, ($UO_3$ 61.2, CuO 8.4, P_2O_5 15.1, H_2O 15.3 per cent.).

GENERAL DESCRIPTION.—Thin square tetragonal plates of bright green color and pearly lustre. Sometimes in pyramids or micaceous aggregates.

PHYSICAL CHARACTERS.—Translucent. Lustre, pearly. Color, emerald to grass green. Streak, pale green. H., 2 to 2.5. Sp. gr., 3.4 to 3.6. Brittle.

BEFORE BLOWPIPE, ETC.—Fuses easily to a black mass and colors the flame green. In borax yields a green glass in O. F., which becomes opaque red in R. F. Soluble in nitric acid to a yellowish green solution.

THE MOLYBDENUM MINERALS.

The minerals described are:

Sulphide	**Molybdenite**	MoS_2	Hexagonal
Oxide	*Molybdite*	MoO_3	Orthorhombic

Besides these molybdenum occurs as the acid constituent of wulfenite described on page 265.

The metal has an increasing use in the production of an alloy with steel. Its chief important compounds are sodium molybdate, used to impart a blue color to pottery and in dyeing silks and woolens, and molybdic acid from which useful chemical reagents are prepared in the laboratory.

MOLYBDENITE.

COMPOSITION.—MoS_2, (Mo 60.0, S 40.0 per cent.).

GENERAL DESCRIPTION.—Thin graphite-like scales or foliated masses of metallic lustre and bluish gray color, easily separated into flexible non-elastic scales. Sometimes in tabular hexagonal forms and fine granular masses. Soft, unctuous and marks paper.

Physical Characters. H., 1 to 1.5. Sp. gr., 4.6 to 4.9.

LUSTRE, metallic.	OPAQUE.
STREAK, greenish.*	TENACITY, sectile to malleable.
COLOR, bluish lead gray.	CLEAVAGE, basal.

BEFORE BLOWPIPE, ETC.—In forceps infusible, but at high heat colors the flame yellowish green. On charcoal gives sulphurous odor and slight sublimate, yellow hot, white cold, and deep blue when flashed with the reducing flame. Soluble in strong nitric acid and during solution on platinum it is luminous. With sulphuric acid yields a blue solution. In salt of phosphorus and borax yields characteristic molybdenum reactions.

SIMILAR SPECIES.—Differs from graphite in streak and blowpipe reactions. May usually be distinguished by its lighter bluish gray color.

REMARKS. — Occurs usually in crystalline rocks, and is not readily altered. It is found in many American localities, especially, Westmoreland, N. H., Blue Hill Bay, Maine, Okanogan Co., Wash., and Pitkin, Colorado. Large deposits occur at Cooper, Maine, and are now being mined.

USES. — It is the source of the molybdenum salts which are important chiefly in analytical work. Recently quite a demand has developed for molybdenum for toughening and hardening steel, it apparently being preferable to tungsten for this purpose.

MOLYBDITE.

COMPOSITION.—MoO_3, (Mo 66.7 per cent.).

GENERAL DESCRIPTION.—An earthy yellow powder or, rarely, tufts and hair-like crystals of yellowish white color.

PHYSICAL CHARACTERS.—Opaque to translucent. Lustre, dull or silky. Color, yellow or yellowish white. Streak, straw yellow. H., 1 to 2. Sp. gr., 4.49 to 4.5.

BEFORE BLOWPIPE, ETC.—On charcoal fuses, yielding crystals yellow hot, white cold, and made deep blue by the reducing flame. In borax and salt of phosphorus gives characteristic molybdenum reactions.

* Best seen on glazed porcelain.

CHAPTER XXVIII.

THE COPPER MINERALS.

THE minerals described are:

Metal	**Copper**	Cu	Isometric
Sulphides	**Chalcocite**	Cu_2S	Orthorhombic
	Bornite	Cu_3FeS_4	Isometric
	Chalcopyrite	$CuFeS_2$	Tetragonal
Sulphoarsenite	**Enargite**	Cu_3AsS_4	Orthorhombic
Sulphoantimonite	**Tetrahedrite**	$Cu_8Sb_2S_7$	Isometric
Oxides	**Cuprite**	Cu_2O	Isometric
	Tenorite	CuO	Triclinic
Basic chloride	*Atacamite*	$Cu(OH)Cl.Cu(OH)_2$	Orthorhombic
Sulphates	*Chalcanthite*	$CuSO_4.5H_2O$	Triclinic
Carbonates	**Malachite**	$Cu_2(OH)CO_3$	Monoclinic
	Azurite	$Cu_3(OH)_2(CO_3)_2$	Monoclinic
Silicates	**Chrysocolla**	$CuSiO_3.2H_2O$	
	Dioptase	H_2CuSiO_4	Hexagonal

In addition to these the iron sulphides often carry copper which is extracted after burning for sulphuric acid.

The chief copper minerals are chalcopyrite and bornite, native copper, cuprite, malachite and azurite, though nearly all the others above mentioned are sufficiently plentiful to be considered as ores. The world's product* of copper in 1902 was 533,763 metric tons of which this country produced 277,047 tons. In 1903 the output of the United States had increased to 304,309 metric tons,† and of the total product of the world, about one-fourth was derived from the sulphide ores of Montana, and one-sixth from the native copper of Michigan. Altogether, the United States yields about two-thirds of the copper annually produced.

The method of extraction of the copper is dependent upon the nature of the ore, and may roughly be classed under three headings:

Treatment of native copper.
Treatment of oxidized ores.
Treatment of sulphides.

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* *Mineral Industries*, 1902, p. 175.
† *Engineering and Mining Journal*, 1904, p. 4.

A great many processes exist or have existed, but these for a general brief discussion may be reduced to a small number of type processes of which the others are variations due to local conditions or constituents of the ore.

Treatment of Native Copper.

Native copper occurs in enormous quantities in Michigan, and the deposits mined average less than two per cent. of copper, although occasionally large masses of the metal are found. The rock is crushed by steam stamps and the copper separated from the rock by the action of water and the use of jigs, tables, and other concentrating apparatus. The concentrated material is then melted in a large reverberatory furnace with limestone and slags from previous operations. The new slag thus formed contains the remaining rock and is removed, leaving behind copper, which after a period of reduction by charcoal and stirring is cast into ingots.

Treatment of Oxidized Ores.

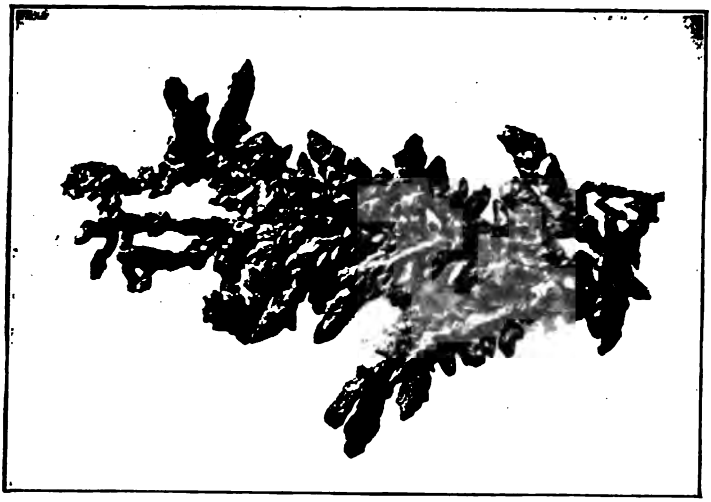
The oxidized ores in Arizona which average over ten per cent. of copper, are smelted in blast-furnaces with coke and the necessary flux to make a slag with the associated gangue. The result is an impure metal called black copper, which is later refined.

Treatment of Sulphides.

The treatment of sulphides is quite varied, depending chiefly on the presence or absence of arsenic, the richness of the ore and the local conditions. The ores always contain iron, copper and sulphur, and may contain arsenic, antimony, silver, gold, etc. All the smelting processes depend on the facts that at high temperatures copper has a greater affinity for sulphur than iron has, and iron a stronger affinity than copper for oxygen. So that if such an ore is subjected to oxidation by roasting, oxides result; but in the subsequent fusion, if enough sulphur has been left, the copper will form a fusible sulphide, and the oxidized iron will unite with the gangue and the flux to form a slag.

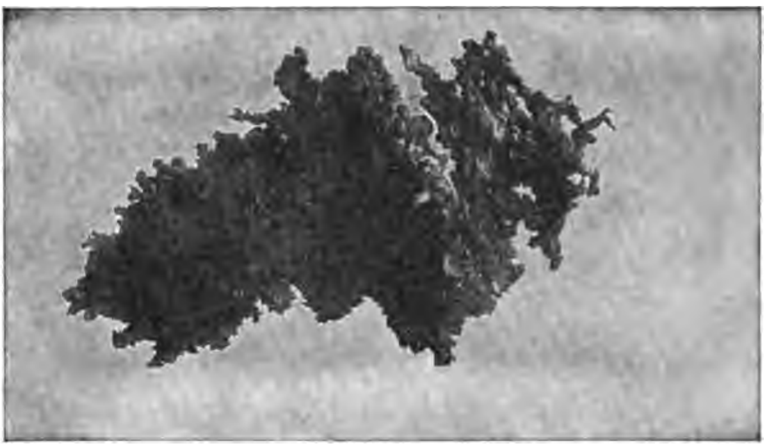
By regulating the roasting, the sulphur contents may be brought to any desired percentage. This may be just sufficient to satisfy the copper or to satisfy also a great deal of the iron producing a low-grade sulphide (matte), which, by re-roasting and refusion, is enriched. The low-grade matte means a smaller loss of copper

FIG. 389.



Copper, Calumet and Hecla Mine, Lake Superior. Columbia University.

FIG. 390.



Copper, Yadkin Gold Mine, N. C. N. Y. State Museum.

in the slags, and is often of service in assisting the removal of arsenic and antimony.

When the matte has reached the required percentage of copper, it is roasted as free from sulphur as possible, and being now essen-

tially an oxide, it may be smelted for copper either in a shaft-furnace, much as the oxidized ores are, or, when silver or gold is present, in a reverberatory furnace.

In a more recent method the ores are roasted and fused, producing a matte containing over fifty per cent. of copper. This matte, while liquid, is run into a sort of Bessemer converter, and a blast turned on, by which the sulphur, arsenic and antimony are driven off, the iron oxidized and converted into slag, and black copper obtained.

The crude copper is refined either by remelting and oxidation, or more frequently electrolytically.

The great uses of copper are in electrical work and in alloys with zinc and tin, such as brass, yellow metal, bronze, bell metal, German silver, etc. In 1903 about 20,000 tons of copper sulphate were made in the United States.

COPPER. — Native Copper.

COMPOSITION. — Cu often containing Ag, sometimes Hg or Bi.

GENERAL DESCRIPTION. — A soft, *red*, malleable metal, with a red streak. Usually in sheets or disseminated masses, varying from small grains to several hundred tons in weight. Also in threads and wire and in distorted crystals and twisted groups.

CRYSTALLIZATION. — Isometric. Tetrahexahedron and cube most frequent, Fig. 392, also twinned, Fig. 393, giving by elongation spear-shaped forms often complexly grouped and usually distorted.

FIG. 391.

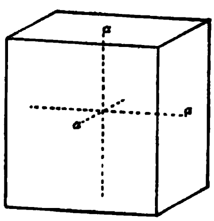


FIG. 392.

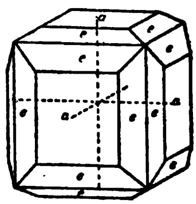
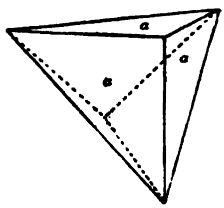


FIG. 393.



Physical Characters. H., 2.5 to 3. Sp. gr., 8.8 to 8.9.

LUSTRE, metallic. OPAQUE.

STREAK, copper red. TENACITY, malleable and ductile.

COLOR, copper red, tarnishing nearly black.

BEFORE BLOWPIPE, ETC.—Fuses easily to a malleable globule, often coated with a black oxide. In beads, becomes in O. F. green when hot; blue, cold, and in R. F. opaque red. Soluble in nitric acid, with evolution of a brown gas, to a green solution, which will deposit copper on iron or steel. The solution becomes deep azure blue on addition of ammonia.

SIMILAR SPECIES.—Resembles niccolite and tarnished silver, differs in copper-red streak.

REMARKS.—Occurs with native silver and ores of copper, and by oxidation may form cuprite or melaconite or the carbonates. In Michigan it occurs in trap or conglomerate. It is especially apt to occur near dikes of igneous rocks. The great locality of the world for native copper, and the only locality still yielding this mineral in large quantities, is the Lake Superior region of Northern Michigan, and although the territory here covered is many square miles in extent, the Calumet and Hecla mine yields the major part of all that is produced. Although native copper is also found in Arizona, California, and, to a limited extent, in other American localities, it is never mined for itself alone, nor does it constitute a large part of the copper ore present. The Coro-Coro mines, in Bolivia, are now producing some copper from the native metal.

USES.—It is an important source of the copper of commerce.

CHALCOCITE.—Copper Glance.

COMPOSITION.—Cu_2S, (Cu 79.8, S 20.2 per cent.).

GENERAL DESCRIPTION.—Black granular or compact masses, with metallic lustre, or sometimes nodules or pseudomorphic after wood. Often coated with the green carbonate, malachite. Also in crystals.

CRYSTALLIZATION.—Orthorhombic, $\breve{a} : \bar{b} : \dot{c} = 0.582 : 1 : 0.970$. $I \wedge I = 119° 35'$. $O \wedge 1 = 117° 24\frac{1}{2}'$. Tabular forms, pseudo-hexagonal or frequently twinned, making star-like groups.

Physical Characters. H., 2.5 to 3. Sp. gr., 5.5 to 5.8.

LUSTRE, metallic. OPAQUE.

STREAK, lead gray. TENACITY, brittle.

COLOR, blackish lead gray, with dull-black tarnish.

BEFORE BLOWPIPE, ETC.—On charcoal, fuses to a globule, yielding sulphur dioxide. With soda, yields a copper button and a strong sulphur reaction. Colors flame emerald green, or if moistened with hydrochloric acid, it colors the flame azure blue. In borax or salt of phosphorus, yields copper beads. Soluble in nitric acid, leaving a residue of sulphur.

SIMILAR SPECIES.—It is more brittle than argentite, and differs from bornite in not becoming magnetic on fusion.

REMARKS.—Chalcocite occurs with other copper minerals and with hematite, galenite and cassiterite. Is found at Butte, Montana, and other American localities of less importance. Fine crystals are obtained from Cornwall, England.

USES. — It is an ore of copper.

BORNITE. — Purple Copper Ore. Horse Flesh Ore.

COMPOSITION. — Cu_5FeS_4, (Cu 63.3, Fe 11.2, S 25.5 per cent.), but often contains admixed chalcocite.

GENERAL DESCRIPTION.—On fresh fracture, bornite is of a peculiar red-brown color and metallic lustre. It tarnishes to deep blue and purple tints, often variegated. Usually massive, sometimes small cubes or other isometric forms.

Physical Characters. H., 3. Sp. gr., 4.9 to 5.4.

LUSTRE, metallic. OPAQUE.
STREAK, grayish black. TENACITY, brittle.
COLOR, dark copper red, brownish or violet blue, often varied.

BEFORE BLOWPIPE, ETC.—Blackens, becomes red on cooling, and finally fuses to a brittle, magnetic globule and evolves sulphur dioxide fumes. In oxidizing flame with borax or salt of phosphorus, gives green bead when hot, greenish blue when cold, the bead is opaque red in the reducing flame. Soluble in nitric acid, with separation of sulphur.

REMARKS.—On account of its high percentage of copper, it is especially valuable as an ore of copper when found in quantity. A large portion of the ore of many of the Chilian mines consists of bornite, and it has been found in quantity in the Montana copper regions. Also found at Bristol, Conn.; Acton, Canada: in Mexico, in Peru and other copper regions.

USES.—It is an important ore of copper.

CHALCOPYRITE.—Copper Pyrites. Yellow Copper Ore.

COMPOSITION.—$CuFeS_2$, (Cu 34.5, Fe 30.5, S 35.0 per cent.), with mechanically intermixed pyrite at times.

GENERAL DESCRIPTION.—A bright brassy yellow mineral of metallic lustre, often with iridescent tarnish resembling that of bornite. Usually massive. Sometimes in crystals.

CRYSTALLIZATION. — Tetragonal. Scalenohedral class, p. 41. Axis $\dot{c} = 0.985$.

Sphenoids predominate, $p =$ unit sphenoid; $o = (a : a : \frac{1}{2}c)$;

$\{772\}$; $t=(a:a:\frac{1}{4}c)$; $\{114\}$; $v=(a:a:4c)$; $\{441\}$; $s=(a:2a:c)$; $\{212\}$.

Supplement angles (over top) $pp = 108° 40'$; $oo = 128° 52'$; $tt = 38° 25'$; $vv = 159° 39'$.

FIG. 394.

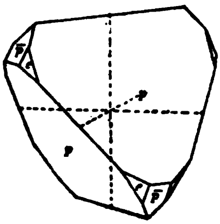
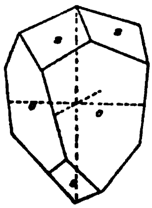
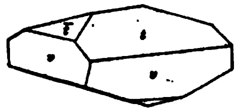


FIG. 395.



French Creek, Pa.

FIG. 396.



Ellenville, N. Y.

Physical Characters. H., 3.5 to 4. Sp. gr., 4.1 to 4.3.

LUSTRE, metallic. OPAQUE.

STREAK, greenish black. TENACITY, brittle.

COLOR, bright brass yellow, often tarnished in blue, purple and black hues.

BEFORE BLOWPIPE, ETC.—On charcoal fuses with scintillation to a brittle magnetic globule. With soda yields metallic malleable red button and sulphur test. In closed tube decrepitates, becomes dark and iridescent and may give deposit of sulphur. Flame and bead reaction like bornite. Soluble in nitric acid with separation of sulphur, and from the solution ammonia throws down a brown precipitate, and leaves the liquid deep blue in color.

SIMILAR SPECIES.—Chalcopyrite is softer and darker in color than pyrite, and differs from gold in black streak and brittleness.

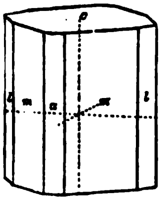
REMARKS.—Chalcopyrite is probably formed in a manner similar to the formation of pyrite which is its frequent associate. Its most prominent associated minerals are the metallic sulphides and copper ores, many of which have been formed by its alteration. It sometimes contains gold or silver. It is a very widely distributed mineral and the major part of all the copper produced is made from it. Prominent mines are in the Butte, Montana, region; and in Bingham Canyon, Utah. Also produced in large quantities, at Falun in Sweden; Rio Tinto, Spain; Sudbury, Canada; and many other important localities.

USES. — It is the great ore of copper.

ENARGITE.

Composition. — Cu_3AsS_4, (Cu 48.3, As 19.1, S 32.6 per cent.). Sometimes with Cu replaced in part by Zn or Fe and As by Sb.

Fig. 397.



Missoula Co., Mont.

General Description.— A black brittle mineral of metallic lustre, occurring usually columnar or granular but sometimes in orthorhombic crystals.

Crystallization. — Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c} = 0.871 : 1 : 0.825$. m = unit prism, $l = (2\breve{a} : \bar{b} : \infty c)$; $\{120\}$. Supplement angles are $mm = 82° 7'$; $ll = 120° 7'$.

Physical Characters. H., 3. Sp. gr., 4.43 to 4.45.

Lustre, metallic.
Streak, blackish gray.
Color, black or blackish gray.
Opaque.
Tenacity, brittle.

Before Blowpipe, Etc.—On charcoal fuses, yields white fumes with garlic odor. With soda yields malleable copper and a reaction for sulphur. In closed tube decrepitates, yields sulphur sublimate, then fuses and yields red sublimate of arsenic sulphide. Soluble in nitric acid.

Remarks.—Enargite occurs with other copper minerals, especially arsenates derived from its alteration. It is found mainly in the mountains of Chili and Peru. Also at Butte, Montana, Gilpin county, Colorado; in South Carolina, Utah and California.

Uses.—It is an ore of copper, and has been extensively mined.

TETRAHEDRITE. — Gray Copper Ore.

Composition. — $Cu_8Sb_2S_7$. Cu often partially replaced by Fe, Zn, Pb, Hg, Ag, and the Sb by As.

General Description. — A fine grained, dark gray mineral of

Fig. 398.

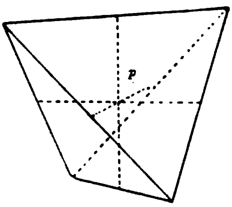


Fig. 399.

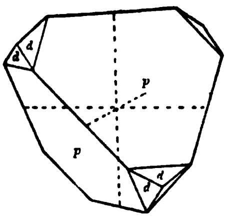
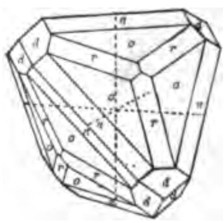


Fig. 400.



metallic lustre. Characterized especially by the tetrahedral habit of its crystals which are sometimes coated with yellow chalcopyrite.

FIG. 401.

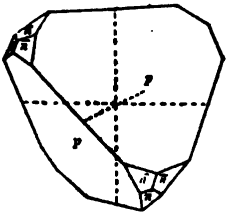
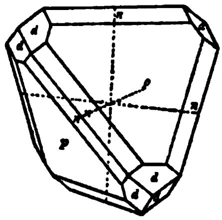


FIG. 402.



CRYSTALLIZATION. — Isometric. Hextetrahedral class, p. 56. The tetrahedron *p*, Fig. 398, usually predominates, often modified by the tristetrahedron $n = (a : 2a : 2a)$; $\{211\}$; Figs. 401, 402, 403, and less frequently by other forms such as the dodecahedron *d*, Figs. 399 and 403, and the deltohedron $r = (a : a : 2a)$; $\{221\}$; Fig. 400.

Physical Characters. H., 3 to 4.5. Sp. gr., 4.5 to 5.1.

LUSTRE, metallic. OPAQUE.
STREAK, black or reddish brown. TENACITY, brittle.
COLOR, light steel to dark lead gray or iron black.

BEFORE BLOWPIPE, ETC.—On charcoal fuses easily to a globule which may be slightly magnetic. Evolves heavy white fumes with sometimes garlic odor. The roasted residue gives bead and flame reactions for copper. Soluble in nitric acid to a green solution with white residue.

VARIETIES—Varieties based upon the replacing metal as mercuric, argentiferous, platiniferous, bismuthiferous, etc., are given special names as *Freibergite*, *Schwatzite*, *Rionite*, etc.

SIMILAR SPECIES.—The crystals are characteristic. The fine grained fracture in conjunction with the color is often sufficient to distinguish it. It is softer than arsenopyrite and the metallic cobalt ores, and does not generally yield a strongly magnetic residue on heating. Bournonite and chalcocite are softer, and finally the blowpipe reactions are distinctive.

REMARKS.—Occurs with the sulphides of lead, silver, copper, etc., especially in Humbolt County, Nevada, and numerous localities in Colorado. Also in Mexico, Bolivia, Chili, and in many parts of Europe.

USES.—It is sometimes worked for silver and also for copper.

Tennanite. — $Cu_8As_2S_7$. This mineral grades into tetrahedrite and is undistinguishable by crystal form or general appearance. It occurs in crystals and is said to occur massive in Utah with enargite.

CUPRITE. — Red Oxide of Copper, Ruby Copper Ore.

COMPOSITION. — Cu_2O (Cu 88.8 per cent.). Sometimes intermixed with limonite.

GENERAL DESCRIPTION.— Fine grained masses, dark red, brownish-red and earthy brick-red in color; or deep red to crimson, transparent, isometric crystals, usually octahedrons, or cubes. Also capillary.

FIG. 403.

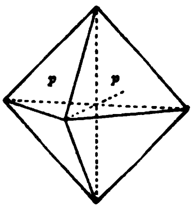


FIG. 404.

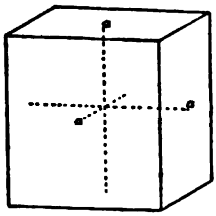
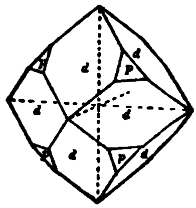


FIG. 405.



CRYSTALLIZATION. — Isometric. Class of gyroid, p. 60. The octahedron *p*, cube *a* and dodecahedron *d* predominating. Index of refraction for red light 2.849.

Physical Characters. H., 3.5 to 4. Sp. gr., 5.85 to 6.15.

LUSTRE, adamantine or dull. TRANSPARENT to opaque.

STREAK, brownish red. TENACITY, brittle.

COLOR, crimson, scarlet, vermilion, or brownish red.

BEFORE BLOWPIPE, ETC.—On charcoal blackens and fuses easily to a malleable red button. Flame and bead tests give the color for copper. Soluble in nitric acid to a green solution. Soluble also in strong hydrochloric acid to a brown solution which diluted with water yields a white precipitate.

SIMILAR SPECIES.—It is softer than hematite and harder than cinnabar or proustite, and differs from them all by yielding an emerald-green flame and a malleable red metal on heating.

REMARKS.—It is formed by oxidation of sulphides or the metal, and is found near the surface associated with limonite, quartz, and copper minerals. It changes to the black oxide and to the carbonates and silicate. In the United States it is especially abundant in the Arizona copper region. Also found in the Lake Superior region, and is abundant in Chili, Peru and Bolivia in association with the other copper ores.

USES.—It is an important ore of copper.

TENORITE.—Melaconite, Black Oxide of Copper.

COMPOSITION.—CuO, (Cu 79.85 per cent.).

GENERAL DESCRIPTION.—Dull black earthy masses, black powder and shining black scales.

PHYSICAL CHARACTERS.—Lustre, metallic in scales, dull in masses. Color and streak black. H., 3. Sp. gr., 5.82 to 6.25.

BEFORE BLOWPIPE, ETC.—Infusible, otherwise like cuprite.

REMARKS.—Occurs in fissures in the lava of Vesuvius, as a black coat on chalcopyrite and as dull black masses with chrysocolla.

ATACAMITE.

COMPOSITION.—$Cu(OH)Cl \cdot Cu(OH)_2$, (Cu 59.45, Cl 16.64 per cent.).

GENERAL DESCRIPTION.—Confused aggregates of crystals of bright or dark-green color. Also granular or compact massive, or as a crust. Rarely in slender orthorhombic prisms.

PHYSICAL CHARACTERS.—Translucent to transparent. Lustre, adamantine to vitreous. Color, bright green, emerald green, blackish green. Streak, apple green. H., 3 to 3.5. Sp. gr., 3.75 to 3.77.

BEFORE BLOWPIPE, ETC. — On charcoal yields white fumes and a coating which is brown near the assay and white at some distance from it, fuses to a copper-red, malleable button, and colors the flame a beautiful and persistent blue *without the aid of hydrochloric acid.* In closed tube yields water and a gray sublimate. Soluble in acids to a green solution.

CHALCANTHITE.—Blue Vitriol.

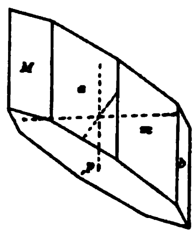
COMPOSITION.—$CuSO_4 \cdot 5H_2O$, (CuO 31.8, SO_3 32.1, H_2O 36.1 per cent.).

GENERAL DESCRIPTION.—A blue, glassy mineral, with a disagreeable metallic taste. It occurs usually as an incrustation, with fibrous, stalactitic or botryoidal structure; but sometimes in flat triclinic crystals.

PHYSICAL CHARACTERS.—Translucent. Lustre, vitreous. Color, deep blue to sky blue. Streak, white. H., 2.5. Sp. gr., 2.12 to 2.30. Brittle. Taste, metallic nauseous.

CRYSTALLIZATION. — Triclinic. Axes $\breve{a} : \bar{b} : \dot{c} = 0.566 : 1 : 0.551$. Axial angles $\alpha = 82° 21'$; $\beta = 73° 11'$; $\gamma = 77° 37'$. Prominent forms, right and left unit prisms *m* and *M*, unit pyramid *p*, and the pinacoids *a* and *b*. Angles $mM = 56° 50'$. Optically —.

FIG. 406.



BEFORE BLOWPIPE, ETC. — On charcoal, fuses, coloring flame green and leaving metallic copper. In closed tube yields water and sulphur dioxide and leaves a white powder. Easily soluble in water to a blue solution.

REMARKS. — It is produced by oxidation of the sulphides, especially chalcopyrite. Copper is sometimes precipitated from mine waters containing chalcanthite.

Brochantite. — $CuSO_4 \cdot 3Cu(OH)_2$. Velvety, emerald-green crusts of fine needle crystals and botryoidal masses.

Liebethenite. — $Cu_2(OH)PO_4$. Dark, olive-green mineral, usually in druses of short prismatic orthorhombic crystals, more rarely compact.

Olivenite. — $Cu_2(OH)AsO_4$. Needle-like orthorhombic crystals of dark olive-green, also nodules and fibrous or velvety masses of light-green to gray or brown color.

MALACHITE.—Green Carbonate of Copper.

COMPOSITION.—$Cu_2(OH)_2CO_3$, (CuO 71.9, CO_2 19.9, H_2O 8.2 per cent.)

GENERAL DESCRIPTION.—Bright-green masses and crusts, often with a delicate, silky fibrous structure or banded in lighter and darker shades of green. Sometimes stalactitic. Also in dull-green, earthy masses, and rarely in small, slender, monoclinic crystals. Frequently coating other copper minerals or filling their crevices and seams.

Physical Characters. H., 3.5 to 4. Sp. gr., 3.9 to 4.03.
LUSTRE, silky, adamantine or dull. TRANSLUCENT to opaque.
Streak, pale green. TENACITY, brittle.
COLOR, bright emerald to grass green or nearly black.

BEFORE BLOWPIPE, ETC.—On charcoal, decrepitates, blackens, fuses, and colors the flame green, leaving a globule of metallic copper. In closed tube, blackens and yields water and carbon dioxide. Soluble in acids, with effervescence.

SIMILAR SPECIES.—Distinguished by color and effervescence with acids.

REMARKS.—Malachite is formed by action of carbonated waters on other copper minerals. It is found chiefly with these or pseudomorphous after them, especially after cuprite and azurite. Immense deposits occur at Bisbee, Arizona, and other localities in the same region. Also in large deposits in Siberia, Chili and Australia. In smaller quantities it is found in the vicinity of all copper ores.

USES.—Is an ore of copper, and like marble is polished for ornamental articles, table-tops, etc.

AZURITE. — Blue Carbonate of Copper.

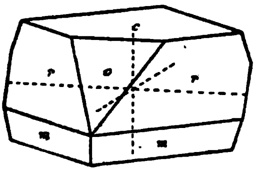
COMPOSITION. — $Cu_3(OH)_2(CO_3)_2$, (CuO 69.2, CO_2 25.6, H_2O 5.2 per cent.).

GENERAL DESCRIPTION. — A dark-blue mineral occurring in highly modified, glassy, monoclinic crystals and groups. When massive, it may be vitreous, velvety, or dull and earthy. It frequently occurs incrusting other copper ores, or distributed through their cracks and crevices.

CRYSTALLIZATION. — Monoclinic. Axes $\grave{a} : \bar{b} : c = 0.850 : 1 : 0.881$; $\beta = 87° \; 36'$.

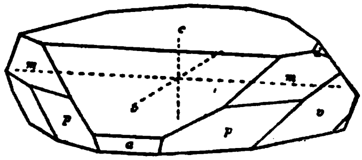
Crystals very varied in habit. Those figured show basal pina-

FIG. 407.



Arizona.

FIG. 408.



Chessy, France.

coid *c*, ortho-pinacoid *a*, unit prism *m*, unit dome *o*, and the pyramids *p*, *r*, and *v*. Supplement angles are $mm = 80° \; 41'$; $co = 44° \; 46'$. Optically +.

Physical Characters. H., 3.5 to 4. Sp. gr., 3.77 to 3.83.

LUSTRE, vitreous. TRANSLUCENT to opaque.
STREAK, blue. TENACITY, brittle.
COLOR, dark blue to azure blue.

BEFORE BLOWPIPE, ETC.—As for malachite.

REMARKS.—Origin, associates and localities are the same as for malachite.

USES.—As an ore of copper and a rather unsatisfactory blue paint.

CHRYSOCOLLA.

COMPOSITION.—$CuSiO_3 + 2H_2O$. Often very impure (CuO 45.2, SiO_2 34.3, H_2O 20.5 per cent.).

GENERAL DESCRIPTION.—Green to blue incrustations and seams often opal-like in texture, or sometimes, from impurities, resembling a kaolin colored by copper. Also brown, resembling limonite, and in dull green earthy masses. Never found in crystals.

Physical Characters. H., 2 to 4. Sp. gr., 2 to 2.3.

LUSTRE, vitreous, dull. TRANSLUCENT to opaque.
STREAK, white. TENACITY, brittle.
COLOR, green to light blue, brown when ferriferous.

BEFORE BLOWPIPE, ETC.—In forceps or on charcoal is infusible, but turns black, then brown and colors the flame emerald green. In

bead, reacts for copper. With soda, yields malleable copper. In closed tube, yields water. Decomposed by hydrochloric acid, leaving a residue of silica. Boiled with KOH, yields a blue solution, from which excess of NH_4Cl precipitates flocculent H_2SiO_3.

SIMILAR SPECIES.—It is softer than turquois or opal and does not effervesce like malachite.

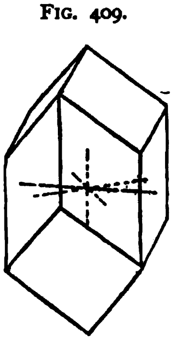
REMARKS.—Chrysocolla occurs with other copper minerals, especially near the tops of veins. It is probably formed by the action of hot solutions of alkaline silicates on other copper ores. Found at Clifton, Arizona; Hartville, Wyoming, and in most of the prominent copper-bearing regions.

USES.—As an ore of copper and an imitation turquois.

DIOPTASE.

COMPOSITION.—H_2CuSiO_4, (CuO 50.4, SiO_2 38.2, H_2O 11.4 per cent.).

FIG. 409.



GENERAL DESCRIPTION.—Glassy, emerald-green crystals and druses of indistinct crystals. Also found massive.

CRYSTALLIZATION.—Hexagonal, $\dot{c} = 0.534$. $R \wedge R = 125° 55'$. $2 \wedge 2 = 95° 26\frac{1}{2}'$. Commonly prismatic, with rhombohedral terminations.

PHYSICAL CHARACTERS. Transparent to opaque. Lustre, vitreous. Color, emerald green. Streak, green. H, 5. Sp. gr., 3.28 to 3.35. Brittle. Cleavage, rhombohedral.

BEFORE BLOWPIPE, ETC.—Decrepitates, blackens, colors the flame emerald green but is infusible. In closed tube, blackens and yields water. Gelatinizes with acids.

CHAPTER XXIX.

MERCURY AND SILVER MINERALS.

THE MERCURY MINERALS.

THE minerals described are:

Metal	*Mercury*	Hg	
Sulphide	**Cinnabar**	HgS	Hexagonal
Chloride	*Calomel*	Hg_2Cl_2	Tetragonal

The only ore is cinnabar, with which the native metal sometimes occurs in small quantities. The ore is usually low grade, that mined in this country yielding an average of less than one per cent. of mercury. The world's product of mercury in 1902 was about 3,000 metric tons, of which the United States produced one-third. In 1903 the output of the United States was 1,010 metric tons.*

Mercury is obtained from cinnabar by heating the larger lumps in a shaft-furnace, resembling a continuous lime kiln, with three exterior fire places. A little fuel is also mixed with the ore. The heat decomposes the sulphide, forming fumes of sulphur dioxide and mercury. These fumes are carried off through large iron pipes to condensers where the mercury is liquified. The finer ore is heated in a vertical shaft containing a series of inclined shelves down which the ore slips whenever any is drawn off at the bottom. The fumes go to the condensers already mentioned.

Mercury is extensively used in certain processes for the extraction of gold and silver from their ores and in the manufacture of vermilion. Minor uses are in barometers, thermometers, silvering mirrors, and in medicine.

MERCURY.

COMPOSITION.—Hg, with sometimes a little silver.

GENERAL DESCRIPTION.—A tin white liquid with metallic lustre. Usually found in little globules scattered in the gangue, or in cavities with cinnabar or calomel.

PHYSICAL CHARACTERS.—Opaque liquid. Lustre, metallic. Color, tin white. Sp. gr., 13.59.

BEFORE BLOWPIPE, ETC.—Entirely volatile. In matrass or closed tube may be collected in small globules. Soluble in nitric acid.

* *Engineering and Mining Journal*, 1904, p. 4.

CINNABAR.—Natural Vermilion.

Composition.—HgS, (Hg 86.2 per cent.).

General Description.—Very heavy, bright vermilion to brownish red masses of granular texture; more rarely small transparent rhombohedral crystals, or bright scarlet powder, or earthy red mass. Sometimes nearly black from organic matter.

Physical Characters. H., 2 to 2.5. Sp. gr., 8 to 8.2.

Lustre, adamantine to dull. Opaque to transparent.
Streak, scarlet. Tenacity, brittle to sectile.
Color, cochineal red, scarlet, reddish brown, blackish.

Before Blowpipe, Etc. — Completely volatilized without fusion if pure. With soda gives sulphur reaction. In closed tube yields a black sublimate, which becomes red when rubbed; if soda is used a metallic mirror is obtained instead of the black sublimate, and by rubbing with a splinter of wood globules of mercury may be collected. If cinnabar powder is moistened with hydrochloric acid and rubbed on *bright* copper the copper is made silver white. Soluble in aqua regia.

Similar Species. — Cinnabar is softer and heavier than hematite, cuprite, and rutile. It has a more decided red streak than crocoite or realgar, and differs from proustite in density and blowpipe reactions.

Remarks. — Cinnabar occurs in slates and shales, and sometimes in granite or porphyry associated with sulphides of iron, copper, antimony, and arsenic, and with native gold. Its chief localities are Idria, southern Austria; Almaden, Spain; Huancavelica, Peru; Kwei-chan, China; Ekaterinoslav, Russia, and at several places in Lake, San Benito, Napa, and Santa Clara counties, California. Cinnabar is also mined at Terlingua, Texas, and Bald-Butte, Oregon. The United States is now the largest producer.

Uses.—It is the only important ore of mercury. The artificial cinnabar is the important pigment vermilion.

CALOMEL.—Horn Mercury.

Composition.—Hg_2Cl_2, (Hg 84.9 per cent.).

General Description.—A gray or brown translucent mineral of the consistency of horn. Usually found as a coating in cavities with or near cinnabar. Sometimes in well-developed tetragonal forms $\dot{c} = 1.723$.

Physical Characters.—Translucent. Lustre, adamantine. Color, gray, white, brown. Streak, white. H., 1 to 2. Sp. gr., 6.48. Very sectile.

Before Blowpipe, Etc.—Volatilizes without fusion, yielding a white coating. In closed tube with soda forms a metallic mirror.

THE SILVER MINERALS.

The minerals described are:

Metal	**Silver**	Ag	Isometric
	Amalgam	Ag_2Hg_3 to $Ag_{36}Hg$	Isometric
Sulphides	**Argentite**	Ag_2S	Isometric
	Stromeyerite	CuAgS	Orthorhombic
Telluride	**Hessite**	$Ag_2.Te$	Isometric
Sulphoarsenite	**Proustite**	Ag_3AsS_3	Hexagonal
Sulphoantimonites	**Pyrargyrite**	Ag_3SbS_3	Hexagonal
	Stephanite	Ag_5SbS_4	Orthorhombic
	Polybasite	$(Ag.Cu)_9SbS_6$	Orthorhombic
Halides	**Cerargyrite**	AgCl	Isometric
	Bromyrite	AgBr	Isometric
	Embolite	Ag(Br.Cl)	Isometric
	Iodyrite	AgI	Hexagonal

Ordinary silver ores contain less than one per cent. of the silver compounds distributed through various earthy and metallic minerals, and only show the true nature of the silver-bearing substance in occasional rich specimens. Frequently an ore will contain less than twenty ounces of silver per ton.

In 1902* the production of silver was 55,500,000 ounces in this country alone, and the product of the world was 163,936,704 ounces. In 1903 the United States produced 56,519,000 ounces, valued at $30,520,688.†

The extraction of silver by reduction with lead-ores in a water-jacket furnace, and the subsequent treatment has been referred to under lead, p. 256. When silver is a constituent of a copper matte it is recovered as a sedimentary product in the electrolytic refining of the copper. It is collected, together with any gold present, and further purified.

In some instances the silver is extracted from the ore by wet processes or by treatment with mercury.

Several processes for extracting silver by the use of mercury exist, the principle in every case being that mercury will reduce certain compounds of silver to metal and unite with the silver, or if mercury is present and some other substance, as iron or copper, reduces the ore to silver, the mercury will collect it.

The details of amalgamation are in transforming the silver to a condition in which the mercury can act — for instance, forming chlorides by roasting with salt — and in the method of reduction.

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* *Mineral Industry*, 1902, 254.

† *Engineering and Mining Journal*, 1904, p. 5.

In pan amalgamation, so called, the finely-crushed ore, chloridized when necessary, and mixed to a pulp with water, is charged into a tub-like vessel, with an iron bottom and wooden sides. In this tub or pan there revolves a stirrer, with arms shaped to throw the pulp to the sides, from which it rolls back to the centre. Attached to the arms are grinding shoes, which can be lowered so as to rub on the iron bottom or be raised free from it. The practice will differ in detail, but generally the pulp will be kept hot by steam, and no mercury will be added until the grinding is completed. During the grinding the metallic iron of the bottom and the shoes reduces the silver compound; although chemicals, such as salt, copper sulphate, potassium cyanide, etc., are sometimes added to assist. After the grinding the mercury is added, and the stirring continued until the mercury has collected all the silver. The mass is then run into a larger tub, diluted, the mercury amalgam separated, and, by subsequent distillation, the silver recovered from the mercury.

SILVER.—Native Silver.

Composition.—Ag, sometimes alloyed with Au, Cu, Pt, Hg, Sb, Bi.

Fig. 410.

Wire Silver. After Lacroix.

General Description. — A silver-white, malleable metal, occurring in masses, scales and twisted wire-like filaments, Fig. 410,

penetrating the gangue or flattened upon its surface. Sometimes in isometric crystals, occasionally sharp but more frequently elongated and needle-like or in aborescent groups, each branch of which is composed of distorted forms in parallel position.

Physical Characters. H., 2.5 to 3. Sp. gr., 10.1 to 11.1.

LUSTRE, metallic. OPAQUE.

STREAK, silver white. TENACITY, malleable.

COLOR, silver white, tarnishing brown to nearly black.

BEFORE BLOWPIPE, ETC.—On charcoal, fuses to a white metallic globule. Soluble in nitric or sulphuric acid, but from these it is precipitated as a white curd-like precipitate by hydrochloric acid or salt. The precipitate darkens on exposure to light.

SIMILAR SPECIES. — When tarnished, silver resembles copper or bismuth, but is distinguished by its silver-white streak from the former and by malleability and non-volatilization from the latter.

REMARKS.—Silver may have been formed by the reduction of its ores, as it occurs pseudomorphous after them. It is also changed to sulphides by contact with soluble sulphides, and into the chloride by salt water. Its associates are the other silver minerals, and galenite, pyrite, stibnite, tetrahedrite, etc.

The most celebrated mines where native silver is obtained are those of Kongsberg, in Norway, and Huantaya, Peru. Occurs also in Northern Mexico, in the Michigan copper region, in numerous Colorado localities, at Butte, Montana; in Idaho; Arizona, and in smaller quantity in other silver-producing regions.

AMALGAM.

COMPOSITION.—Ag_2Hg_3 to $Ag_{36}Hg$.

GENERAL DESCRIPTION.—A brittle, silver-white mineral of bright metallic lustre, which occurs in imbedded grains and indistinct isometric crystals.

PHYSICAL CHARACTERS.—Opaque, lustre metallic. Color and streak, silver white. H., 3 to 3.5. Sp. gr., 13.75 to 14.1. Somewhat brittle and cuts with a peculiar grating noise.

BEFORE BLOWPIPE, ETC.—On charcoal, partially volatilized, leaving malleable silver. In closed tube, yields mercury mirror. Soluble in nitric acid.

ARGENTITE. — Silver Glance.

COMPOSITION. — Ag_2S, (Ag 87.1 per cent.).

GENERAL DESCRIPTION. — A soft black mineral, of metallic lustre, which cuts like wax and occurs as masses, disseminated grains, or incrusting. Also found as isometric crystals, the cube, octahedron, or dodecahedron being most common and frequently grouped in parallel positions.

Physical Characters. — H., 2 to 2.5. Sp. gr., 7.2 to 7.36.

LUSTRE, metallic. OPAQUE.
STREAK, lead gray. TENACITY, very sectile.
COLOR, lead gray to black or blackish gray.

BEFORE BLOWPIPE, ETC.—On charcoal, swells, fuses, yields fumes of sulphur dioxide, and finally malleable silver. Soluble in nitric acid, with separation of sulphur.

SIMILAR SPECIES.—Differs from other soft black minerals in cutting like wax and in yielding malleable silver on heating. Differs from cerargyrite in solubility in nitric acid.

REMARKS.—Occurs sparingly with other silver minerals as pure material, but is probably the compound of silver so frequently included in galenite, sphalerite, etc. Large amounts of argentite have been obtained in Nevada, especially from the Comstock lode and the Austin mines. Also in Arizona. It is a common ore in Mexico, Chili, Peru and Bolivia.

USES.—It is an ore of silver.

STROMEYERITE.

COMPOSITION. — CuAg S, (Ag 53.1 ; Cu 31.1 per cent.).

GENERAL DESCRIPTION. — Dark gray metallic masses resembling chalcocite. Rarely twinned orthorhombic crystals.

PHYSICAL CHARACTERS. — Opaque. Lustre, metallic. Color, dark gray. Streak, same as color. H., 2.5–3. Sp. gr. 6.2–6.3.

BEFORE BLOWPIPE, ETC. — Reacts for copper, silver and sulphur.

HESSITE.

COMPOSITION.—$(Ag{\cdot}Au)_2Te$, grading from hessite, Ag_2Te (Ag 63 per cent.) to petzite, in which there is 20 to 25 per cent. of gold.

GENERAL DESCRIPTION.—Fine-grained, gray, massive mineral, of metallic lustre. Also coarse granular, and in small, indistinct, isometric crystals.

Physical Characters. H., 2 to 2.5. Sp. Gr., 8.3 to 8.6.

LUSTRE, metallic. OPAQUE.
STREAK, black. TENACITY, slightly sectile.
COLOR, between steel gray and lead gray.

BEFORE BLOWPIPE, ETC.—On charcoal, fuses to a black globule, with white silver points on its surface. If powdered and dropped into boiling concentrated sulphuric acid, the acid is colored an intense purple.

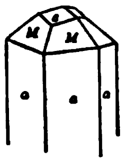
PROUSTITE.—Light Ruby Silver.

Composition.—Ag_3AsS_3, (Ag 65.4, As 15.2, S 19.4 per cent.). Sometimes containing a little antimony.

General Description.—A scarlet vermilion mineral, either translucent or transparent, with a scarlet streak. Usually occurs disseminated through the gangue or as a stain or crust. Rarely in small hexagonal crystals.

Crystallization.— Hexagonal. Hemimorphic class, p. 46. Axis $\dot{c} = 0.804$. Fig. 412 shows a typical crystal according to Miers. Optically —, with very high indices of refraction ($\gamma = 2.979$ for red light).

Fig. 412.



Physical Characters. H., 2 to 2.5. Sp. gr., 5.57 to 5.64.

Lustre, adamantine, brilliant. Translucent to transparent.
Streak, scarlet. Tenacity, brittle.
Color, scarlet vermilion.

Before Blowpipe, Etc.—On charcoal, fuses, yields sulphurous and garlic odors and malleable silver. In closed tube, fuses and yields slight red sublimate, yellow when cold. Decomposed by nitric acid, leaving a white residue. In powder, is turned black by potassium hydroxide solution, and partially dissolved on boiling. Hydrochloric acid precipitates from this a lemon yellow arsenic sulphide.

Similar Species.—Differs from pyrargyrite in scarlet streak, and from cuprite and cinnabar by garlic odor when heated.

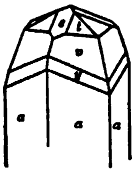
Remarks.—Occurs with other silver minerals, and is mined as an ore of silver. Most abundant in the United States at Poor Man's Lode, Idaho; Austin, Nevada, and in Gunnison County, Colorado, at the Ruby silver district; in large quantities at Guanajuato, Mexico; at Chañarcillo, Chili, and other South American localities. Noted European localities are Andreasberg, Freiberg, and Joachimsthal in the Harz.

PYRARGYRITE.—Dark Ruby Silver.

Composition.—Ag_3SbS_3, (Ag 59.9, Sb 22.3, S 17.8 per cent.). Often with small amounts of arsenic.

General Description.—A nearly black mineral, which is deep red by transmitted light and has a purplish-red streak. Usually occurs massive or disseminated, or in thin films, sometimes in crystals.

FIG. 413.



CRYSTALLIZATION. — Hexagonal. Hemimorphic class, p. 46. Axis $c = 0.789$. Prismatic crystals, with rhombohedral or scalenohedral terminations. Frequently twinned. Fig. 413 shows a typical crystal according to Miers. Optically —, with very high indices of refraction ($\gamma = 3.084$ for red light).

Physical Characters. H., 2.5. Sp. gr., 5.77 to 5.86.

LUSTRE, metallic, adamantine. TRANSLUCENT to opaque.

STREAK, purplish red. TENACITY, brittle.

COLOR, black or nearly so, but purple red by transmitted light.

BEFORE BLOWPIPE, ETC.—On charcoal, fuses easily, spirts, evolves dense white fumes and leaves malleable silver. A white sublimate forms. In closed tube, yields black sublimate, red when cold. Soluble in nitric acid, with separation of sulphur and antimony trioxide. In powder, is turned black by a solution of potassium hydroxide, and on boiling it is decomposed; the solution deposits an orange precipitate on addition of hydrochloric acid.

SIMILAR SPECIES. — The streak is purplish red, differing from the scarlet of proustite. The streak and silver reaction distinguish it from cuprite, cinnabar and realgar.

REMARKS —Occurs with other silver minerals and with arsenic. arsenopyrite, tetrahedrite, galenite, etc. Localities same as for proustite, with which it is usually associated.

USES.—It is an important ore of silver.

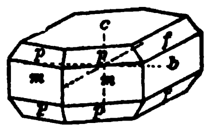
STEPHANITE.—Brittle Silver Ore.

COMPOSITION.—Ag_5SbS_4, (Ag 68.5, Sb 15.2, S 16.3 per cent.).

GENERAL DESCRIPTION.—Fine-grained, iron-black mineral, with metallic lustre, often disseminated through the gangue. Sometimes in short six-sided prismatic crystals. It is soft, but brittle.

CRYSTALLIZATION. — Orthorhombic. Axes $\breve{a} : \bar{b} : c = 0.629 : 1 : 0.685$. Short prismatic crystals often twinned in pseudo-hexagonal shapes. Unit pyramid p, unit prism m, the pinacoids b and c and the dome $f = (\infty \breve{a} : \bar{b} : 2c)$; $\{021\}$; are the commoner forms. Supplement angles $mm = 64° 21'$; $pp = 49° 44'$; $cf = 53° 53'$.

FIG. 414.



Physical Characters. H., 2 to 2.5. Sp. gr., 6.2 to 6.3.

LUSTRE, metallic. OPAQUE.

STREAK and COLOR, black. TENACITY, brittle.

BEFORE BLOWPIPE, ETC.—On charcoal, fuses easily, yielding white fumes and coat and odor of sulphur dioxide, finally leaves malleable silver. Soluble in nitric acid, with residue of sulphur and antimony trioxide. With potassium hydroxide, reacts like pyrargyrite.

SIMILAR SPECIES.—It is more brittle than argentite and softer than tetrahedrite.

REMARKS.—Occurs with other silver ores. It is of common occurrence in the Nevada silver mines, and also at Guanajuanto, Mexico, and at Chañarcillo, Chili. Found also in the mines of Idaho and in those of Saxony, Bohemia and Hungary.

POLYBASITE.

COMPOSITION.—$(Ag.Cu)_9SbS_6$, often with some Sb replaced by As.

GENERAL DESCRIPTION.—A soft, iron-black mineral, of metallic lustre, best known in six-sided tabular prisms, with bevelled edges. In thin splinters it is cherry red by transmitted light. Orthorhombic.

PHYSICAL CHARACTERS.—Nearly opaque. Lustre metallic. Color and streak, black. H., 2 to 3. Sp. gr., 6 to 6.2. Brittle.

BEFORE BLOWPIPE, ETC.—Fuses with spirting. Gives off odor of garlic sometimes, but always yields heavy white fumes and odor of sulphur dioxide, and leaves malleable button, which in beads reacts for copper, or, if dissolved in nitric acid, will yield a flocculent white precipitate on addition of hydrochloric acid. In closed tube, fuses very easily, but yields no sublimate. Soluble in nitric acid.

CERARGYRITE.—Horn Silver.

COMPOSITION.—AgCl, (Ag 75.3 per cent.).

GENERAL DESCRIPTION.—A soft, grayish-green to violet crust or coating of the consistency and lustre of horn or wax. Rarely in cubic crystals.

Physical Characters. H., 1 to 1.5. Sp. gr., 5 to 5.5.

LUSTRE, waxy, resinous. TRANSLUCENT.

STREAK, shining white. TENACITY, very sectile.

COLOR, pearl gray or greenish, darkens on exposure to light, becoming violet, brown or black.

BEFORE BLOWPIPE, ETC.—Fuses very easily, yields acrid fumes and a globule of silver. Rubbed on a moistened surface of zinc

or iron, it swells, blackens and the surface is silvered, and the mineral is reduced to spongy metallic silver. In matrass, with acid potassium sulphate, yields a globule, yellow hot, white cold, and made violet or gray by sunlight. Insoluble in acids, soluble in ammonia. On coal, with oxide of copper, yields azure-blue flame.

SIMILAR SPECIES.—Bromyrite, embolite and iodyrite are most easily distinguished by tests with acid potassium sulphate. It differs from argentite in color and insolubility in nitric acid.

REMARKS.—Occurs usually near the top of veins, and is probably precipitated from silver-bearing solutions by chlorides in surface waters. In the United States its most celebrated localities have been Poor Man's Lode, Horn Silver and certain Idaho mines and the mines at Austin, Nevada. Found also in proportionally large quantities in many of the Mexican and Chilian mines.

USES.—It is a very important ore of silver.

BROMYRITE.—Bromargyrite.

COMPOSITION.—AgBr, (Ag 57.4 per cent.).

GENERAL DESCRIPTION.—Like cerargyrite, except that the color is bright yellow to grass green or olive green. H., 2 to 3. Sp. gr., 5.8 to 6. Usually found in small concretions and little altered by exposure.

BEFORE BLOWPIPE, ETC.—Like cerargyrite, except that in matrass with acid potassium sulphate a little bromine vapor is evolved, coloring the fluid salt yellow, and the fused bromyrite sinks as a dark red, transparent globule, which, on cooling, becomes opaque and deep yellow, and when exposed to sunlight becomes dark green.

EMBOLITE.

COMPOSITION.—Ag(Cl.Br). Isomorphic mixtures of the chloride and bromide.

GENERAL DESCRIPTION.—Intermediate between cerargyrite and embolite. Color, green to yellow, darkening on exposure. H., 1 to 1.5. Sp. gr., 5.31 to 5.81.

BEFORE BLOWPIPE, ETC.—The acid potassium sulphate fusion is like that of cerargyrite or that of bromyrite, as the bromine is small in amount or plentiful.

IODYRITE.—Iodargyrite.

COMPOSITION.—AgI, (Ag 46, I 54 per cent.).

GENERAL DESCRIPTION.—A yellow or yellowish-green, wax-like mineral, occurring massive or in thin flexible scales or in hexagonal crystals.

PHYSICAL CHARACTERS.—Translucent. Lustre, resinous, wax-like. Color, gray, yellow or yellowish green. Streak yellow. H., 1. Sp. gr., 5.6 to 5.7. Sectile.

BEFORE BLOWPIPE, ETC.—Fuses very easily, spreads out and gives pungent odor. In closed tube, fuses and becomes deep orange in color, but cools yellow. With oxide of copper, colors flame intense green. In matrass with acid potassium sulphate, yields violet vapor and deep-red globule, which is yellow when cold and not changed by exposure to sunlight.

CHAPTER XXX.

GOLD, PLATINUM AND IRIDIUM MINERALS.

THE GOLD MINERALS.

THE minerals described are:

Metal	**Gold**	Au	Isometric
Tellurides	**Sylvanite**	(Au.Ag)Te_2	Monoclinic
	Calaverite	$AuTe_2$	
	Krennerite	$AuTe_2$	Orthorhombic

Aside from vein and placer deposits of native gold, the metal is obtained to a very considerable extent from the minerals pyrite, arsenopyrite and pyrrhotite, and from other sulphides or tellurides. In 1903 there was produced * in the United States 3,600,645 fine ounces of gold worth $74,425,340 which was nearly one-fourth of the world's production of $327,000,000. About three-fourths of the total output was used in coinage and the remainder in the arts.

A large proportion of the world's gold is found in superficial deposits called placers, which are beds of sand, gravel or boulders accumulated from the erosion of higher rocks containing gold veins. In working shallow placers the dirt is thrown into a wooden trough several hundred feet long, through which a stream of water is flowing. At the bottom of the trough or "sluice" are placed cross-bars or blocks of wood, or sometimes a pavement of flat stones set on edge is constructed. Near the head of the sluice mercury is added at a regular rate, and this encountering the gold unites with it, and the heavy gold and heavy amalgam are caught in the interstices of the wood or stone pavement, while the lighter material is washed away. At intervals the stream is stopped, the bars or blocks removed and the amalgam collected. By heating in a retort the mercury is distilled from the gold.

Deep placers are sometimes treated by what is called hydraulic mining, which differs from the preceding chiefly in the magnitude of the work and the fact that the water is used in great volume and at heavy pressure, not simply to carry the material down the sluice but also to tear down and wash away the placer. Frequently this

* *Eng. and Min. Jour.*, 1904, p. 4.

is preceded by driving a tunnel into the bottom of the placer and exploding heavy charges of powder to loosen the gravel bank.

Gold that is found in place is usually in quartz veins associated with sulphides, especially pyrite. It is extracted by finely crushing the vein rock and collecting the gold by mercury or copper plates coated with mercury. The vein material is usually stamped in a mortar by blows of several pestles, usually five, raised successively by cams and dropped. Generally water and mercury are in the mortar, and as the material becomes sufficiently fine the water carries it through a screen over a series of amalgamated plates which catch most of the gold. From time to time the amalgam is scraped off of the plates and collected from the mortar and retorted.

Gold-bearing pyrite is usually stamped as described, but the residues which still carry some gold are frequently concentrated, roasted, and chlorinated. Gold tellurides are also generally roasted, ground and chlorinated. That is, the roasted ore is subjected to the action of chlorine and the gold is converted into a chloride, soluble in water. The chlorine may be generated by a mixture of salt, pyrolusite and sulphuric acid, or by a mixture of sulphuric acid and chloride of lime. After dissolving out the chloride of gold with water the gold may be precipitated as metal by ferrous sulphate or as sulphide by hydrogen sulphide. In the latter case the precipitate is pressed, dried, roasted, and finally fused.

A more recent method is to submit the finely crushed ore, which has previously been roasted, if sulphide or telluride, to a weak solution of potassium cyanide. With the aid of the oxygen of the air, or of some oxidizing agent, the potassium cyanide dissolves the gold. The solution is then drawn off into large vats where the gold is precipitated by means of zinc turnings or the gold may be separated electrolytically. The method has become of the greatest importance and comparatively poor ores and tailings from the amalgamation process are very successfully treated by it.

GOLD. — Native Gold.

COMPOSITION. — Au, usually alloyed with Ag, and sometimes Cu, Bi, Rh, or Pd.

GENERAL DESCRIPTION. — A soft malleable metal with color and

streak varying from golden yellow to yellowish white according to the silver contents. It is found in nuggets, grains, or scales, usually so disseminated as to be apparent only on assay. Rarely in distinct isometric crystals, but more frequently in skeleton crystals or

FIG. 415.

Gold, Butte Co., Col. Columbia University.

distorted and passing into wire-like, net-like, and dendritic shapes. Also occurs included in pyrite, sphalerite, galenite, pyrrhotite, and arsenopyrite.

Physical Characters. H., 2.5 to 3. Sp. gr., 15.6 to 19.3.

LUSTRE, metallic.	OPAQUE.
STREAK, like color.	TENACITY, malleable.
COLOR, golden yellow to nearly silver white.	

BEFORE BLOWPIPE, ETC.—On charcoal fuses to a bright yellow button insoluble except in aqua regia. Any silver present will separate from the solution as a white curd-like precipitate. If the solution is evaporated to a thick syrup and diluted with water and heated with stannous chloride it becomes purple, and a purple precipitate settles.

SIMILAR SPECIES.—Chalcopyrite, pyrite, and scales of yellow mica are mistaken for gold, but differ entirely in specific gravity, streak, brittleness, and solubility in acids.

REMARKS.—Occurs in infinitesimal amount in practically all rocks and soil, and even when in paying quantities is commonly only revealed by an assay. The solvent action of superheated water collects and redeposits the gold in more concentrated state, usually in quartz veins associated with or contained in pyrite, arsenopyrite, chalcopyrite, galenite, pyrrhotite, magnetite, hematite, bismuth, tellurium minerals, etc. It is practically unchangeable, but the wearing away of the containing rocks and the sorting and transportation of the fragments with the solution of the solvent portions results in the formation of gold-bearing gravels, river beds, etc.

The four largest gold producing States are California, Colorado, South Dakota and Montana. Besides these American localities the mines of Victoria and New South Wales, Australia, those on the eastern coast of South Africa, and the Siberian mines are the largest gold producers. Many other countries yield smaller amounts.

USES.—The chief uses are for coinage and jewelry.

THE GOLD TELLURIDES. — Sylvanite, Calaverite, Krennerite.

COMPOSITION. — Varying from sylvanite $(Au.Ag)Te_2$ to calaverite or krennerite, $AuTe_2$. (Au 25 per cent. to 40 per cent.)

GENERAL DESCRIPTION. — The gold tellurides are steel gray to silver white minerals, sometimes inclined to yellow. They are usually found incrusting or in small veins in the gangue. Sylvanite and krennerite are found at times in small crystals. All are made yellow by heating.

Physical Characters. H., 1.5 to 2.5. Sp. Gr. 7.9 to 9.04.

LUSTRE, metallic. OPAQUE.

STREAK, like color. TENACITY, brittle.

COLOR, silver white, steel gray and light yellow.

BEFORE BLOWPIPE, ETC. — On charcoal fuse to a gray button which after long heating yields a light yellow bead of gold alloyed with silver which is soluble in aqua regia with a curd-like white precipitate. During fusion a white sublimate forms which will color the flame green, but which if scraped together, placed on porcelain, moistened with conc. H_2SO_4 and heated, becomes rose colored or violet. In the open tube yields a white sublimate which melts to clear transparent drops. Soluble in nitric acid.

REMARKS. — Gold tellurides are the chief ores of the Cripple Creek district in Colorado and as found there contain but little silver. Tellurides occur also in other localities in Colorado, California, Hungary and New South Wales.

THE PLATINUM AND IRIDIUM MINERALS.

The minerals described are:

Metal	**Platinum**	Pt	Isometric
	Iridosmine	(Ir.Os)	Hexagonal
Arsenide	*Sperrylite*	$PtAs_2$	Isometric

Purified platinum is largely used in incandescent lamps, in dental practice for attaching artificial teeth to the plate, in laboratory apparatus, in stills for sulphuric acid and to a more limited extent in jewelry, in electrical contact points, in photography for platinotype prints, in the so-called "oxidizing of silver," and in the balance wheels of non-magnetic watches.

The greater portion of the metal is obtained by washing placer deposits in the Ural Mountains, and only a little is obtained from other localities. Russia produced 234,878 ounces in 1902.*

Platinum, as it occurs in nature, is always alloyed with iron and other metals, from which it must be separated before it possesses the peculiar properties which make it valuable. The native mineral is first treated with dilute aqua regia, which dissolves out any iron, gold or copper. Then concentrated aqua regia is added to the residue, and the platinum and a small amount of iridium are brought into solution. After evaporation of the excess of acid, ammonium chloride is added, the ammonium-platinic chloride being formed and also a small amount of the iridium salt. This precipitate, on being heated, leaves the metal, which consists almost wholly of platinum, but also carries a small amount of iridium. The metals can be further separated, but for many purposes this alloy is preferable to the pure platinum.

The mineral iridosmine, which occurs only in small grains, is used for pointing gold pens, and, by fusion with phosphorus, is converted into a phosphide of iridium, which is used for pointing tools and stylographic pens, for draw-plates for gold and silver wire and for knife edges in the most delicate balances.

The phosphide, by heating in a bed of lime, is changed to pure iridium, which, alloyed with platinum, is used for the standards of weights and measures.

A process of iridium plating also exists.

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* *Mineral Industry*, 1902, p. 530.

PLATINUM.—Native Platinum.

COMPOSITION.—Pt(Fe), usually with small quantities of Rh, Ir, Pd, Os, Cu, and nearly always with Fe even as high as one-sixth of the whole.

GENERAL DESCRIPTION.—A malleable, steel-gray to white metal, occurring in small grains and nuggets in alluvial sands. Very rarely in small cubes.

Physical Characters. H., 4 to 4.5. Sp. gr., 14 to 19.

LUSTRE, metallic.
STREAK, steel gray.
COLOR, light steel gray.
OPAQUE.
TENACITY, malleable.
Often magnetic.

BEFORE BLOWPIPE, ETC.—Infusible and unaffected by fluxes or any single acid. Soluble in aqua regia.

SIMILAR SPECIES.—Heavier than silver and not soluble in nitric acid.

REMARKS.—Found in alluvial deposits with other refractory minerals, as gold, iridosmine, chromite, corundum, zircon, diamond, etc. Is said to occur in syenite and is sometimes found included in masses of chromite or of serpentine. By far the larger part of the platinum of commerce is obtained from placer deposits in the Ural mountains; Borneo, Brazil, and the United States of Colombia also produce small amounts. It has been identified in many of the gold regions of the United States, but only in small quantities, and the quantity annually produced is insignificant.

Sperrylite. — $PtAs_2$, is a tin-white, brittle and opaque mineral of metallic lustre and is chiefly interesting as being the only native compound of platinum. It is found in minute crystals in small quantities in the nickel bearing pyrrhotite and chalcopyrite of Sudbury, Canada, and in the cupric sulphide, covellite, occurring at the Rambler mine in Wyoming. It is a possible future source of platinum.

IRIDOSMINE.

COMPOSITION.—(Ir.Os), sometimes with Rh, Pt, etc.

GENERAL DESCRIPTION.—A tin-white or gray, metallic mineral, very hard and heavy, and occurring in irregular, flattened grains and hexagonal plates.

PHYSICAL CHARACTERS.—Opaque. Lustre metallic. Color and streak, tin white or gray. H., 6 to 7. Sp. gr., 19.3 to 21.1. Rather brittle.

BEFORE BLOWPIPE, ETC.—Infusible. May yield unpleasant, pungent odor. Insoluble in acids.

CHAPTER XXXI.

POTASSIUM, SODIUM, LITHIUM AND AMMONIUM MINERALS.

THE POTASSIUM MINERALS.

THE minerals described are:

Chlorides	*Sylvite*	KCl	Isometric
	Carnallite	$KCl.MgCl.6H_2O$	Orthorhombic
	Kainite	$KCl.MgSO_4.3H_2O$	Monoclinic
Sulphates	*Kalinite*	$K.Al(SO_4)_2.12H_2O$	Isometric
Nitrate	**Nitre**	KNO_3	Orthorhombic

In addition to these, potassium is a constituent of many silicates, such as orthoclase and muscovite. It is also found in solution in many brines.

The natural potash salts, especially the chlorides, are obtained in large amounts from two or three deposits in Germany. The

FIG. 416.

Sylvite, Stassfurt, Germany. U. S. National Museum.

present annual output of the syndicate controlling these mines is over 3,000,000 tons and it is estimated that at this rate of production the beds will last for thirty-three centuries. The nitrate is

mined in India, and occurs in small amounts elsewhere. Potassium bromide is extracted from the mother liquor of certain brines. The chief important uses are in the form of the nitrate in gunpowder and as the chloride or sulphate in fertilizers. The element is essential to plant growth and is liable to exhaustion in soils.

SYLVITE.

COMPOSITION.—KCl, (K 52.4 per cent.).

GENERAL DESCRIPTION.—Colorless, transparent cubes or white masses, which look like common salt and have somewhat similar taste. Absorbs moisture and becomes damp.

PHYSICAL CHARACTERS.—Transparent when pure. Lustre, vitreous. Color, colorless white, bluish, reddish. Streak, white. H., 2. Sp. gr., 1.97 to 1.99. Taste, like salt. Cleavage in cubes.

BEFORE BLOWPIPE, ETC.—Fuses very readily, coloring flame violet. If added to a salt of phosphorus and copper oxide bead, the flame is colored azure blue. Soluble in water and acids.

CARNALLITE.

COMPOSITION.—$KCl.MgCl + 6H_2O$ (K 14.1 per cent.).

GENERAL DESCRIPTION. — A massive and somewhat granular mineral occurring in beds or strata at the Stassfurt potash salts deposit of Germany. Seldom found in crystals.

PHYSICAL CHARACTERS. — Translucent to transparent. Lustre, sub-vitreous. Color, white, brownish and reddish. Streak, white. H., 1. G = 1.62. Taste, salty and bitter.

BEFORE BLOWPIPE, ETC. — Same as for sylvite. Very deliquescent.

USES. — Is the chief source of the manufactured potash salts of commerce which are so largely used as fertilizers. It is simply dissolved in water and the potassium chloride crystallized out at the proper temperature.

KAINITE.

COMPOSITION. — $MgSO_4.KCl + 3H_2O$.

GENERAL DESCRIPTION. — White to dark red granular crusts with salty taste, also tabular and prismatic monoclinic crystals.

Physical Characters. H., 2.5–3. Sp. gr., 2.05–2.2.

LUSTRE, vitreous. TRANSPARENT to translucent.

STREAK, colorless. TASTE, salty and astringent.

COLOR, white to reddish white, and colorless.

BEFORE BLOWPIPE, ETC. — Easily fusible, coloring the flame violet. After fusion on charcoal in reducing flame the moistened mass will stain bright silver. Soluble in water.

REMARKS. — Occurs in beds of considerable thickness in Stassfurt, Germany, with halite, sylvite, and other soluble salts.

Aphthitalite. — $(K.Na)_2SO_4$. Thin white hexagonal plates or crusts on Vesuvius lavas.

KALINITE. — Potash Alum.

COMPOSITION. — $KAl(SO_4)_2 + 12H_2O$, (K_2O 9.9, Al_2O_3 10.8, SO_3 33.8, H_2O 45.5 per cent.).

GENERAL DESCRIPTION. — Natural alum with the peculiar taste, occurring as a white efflorescence on argillaceous minerals. Usually fibrous, or as mealy crusts, or compact.

PHYSICAL CHARACTERS. — Transparent or translucent. Color, white. Lustre, vitreous. Streak, white. Taste, astringent. Tenacity, brittle. H., 2.5. Sp. gr., 1.75.

BEFORE BLOWPIPE, ETC. — On heating, becomes liquid, yields water, and finally swells to a white, spongy, easily-powdered mass, *which is infusible*, but colors the flame violet. With cobalt solution, becomes deep blue on heating. Soluble in water.

NITRE.—Saltpetre.

COMPOSITION.—KNO_3, (K_2O 46.5, N_2O_5 53.5 per cent.).

GENERAL DESCRIPTION.—White crusts, needle-like, orthorhombic crystals and silky tufts, occurring in limestone caverns or as incrustations upon the earth's surface or on walls, rocks, etc. Not altered by exposure.

Physical Characters. H., 2. Sp. gr., 2.09 to 2.14.

LUSTRE, vitreous.	TRANSLUCENT.
STREAK, white.	TENACITY, brittle.
COLOR, colorless, white, gray.	TASTE, salty and cooling.

BEFORE BLOWPIPE, ETC.—On charcoal fuses easily, deflagrates violently like gunpowder, colors the flame violet. Soluble in water.

REMARKS.—Formed in certain soils by the action of a ferment, especially after rains. Although found in small quantity in many of the so-called alkali lands of our Western States, it is not utilized. Deposits in Ceylon and India are worked, and refined nitre produced, but almost all of the commercial product is made from sodium nitrate and potassium chloride.

THE SODIUM MINERALS.

The minerals described are:

Chloride	**Halite**	$NaCl$	Isometric
Sulphate	*Mirabilite*	$Na_2SO_4.10H_2O$	Monoclinic
Nitrate	**Soda Nitre**	$NaNO_3$	Hexagonal
Carbonate	*Trona*	$Na_2CO_3.HNaCO_3.2H_2O$	Monoclinic

Besides which sodium is an important constituent in plagioclase and many other silicates.

HALITE, or common salt, occurs in beds varying from a few feet to over three thousand feet in thickness. It occurs also in nearly all water, from infinitesimal quantities to strong brines, and it occurs as incrustations on high planes in dry regions. The salt deposits are mined and the brines are pumped up and evaporated by the heat of the sun or by artificial heat. Salt to the amount of 23,849,221 barrels was reported * as produced in 1902.

The amount used is enormous; for instance, over 1,000,000 tons per year are converted into sodium and chlorine compounds, chief among which are sodium carbonate and bicarbonate, caustic soda and bleaching powder.

BROMINE is present, as sodium and potassium bromide, in many salt deposits but makes up only a small fraction of a per cent. of the total. In this country it is obtained mainly from the salt wells of Michigan but also from those of Ohio, West Virginia and Pennsylvania. In 1892 the United States produced 513,890 pounds of bromine and its equivalent in potassium bromide.†

SODA NITRE is found in enormous quantities at Tarapaca, Chili; nearly a million tons a year are exported. It is used in the manufacture of nitre for gunpowder, in the production of nitric acid, but chiefly for fertilizing purposes. It is also the source of most of the IODINE, as the mother liquors after refining may contain twenty per cent. of sodium iodate. Large deposits exist in Death Valley, California. The scarcity of water makes their exploitation difficult.

TRONA.—Carbonates of sodium, mixed carbonates, and bicarbonates occur plentifully in the alkali deserts of the West with sulphates and chlorides. The pools and lakes into which these districts drain contain large amounts of these salts, and by evaporating the water to the required degree of concentration, crystals of soda are deposited, which are refined by subsequent operations.

HALITE.—Rock Salt, Common Salt.

COMPOSITION.—NaCl, (Na 60.6 per cent.), usually impure.

GENERAL DESCRIPTION.—Essentially colorless to white and vitreous, but from iron is frequently brown to red. It occurs in cubic crystals, often with cavernous faces and in masses, with cubical cleavage, and also compact granular and coarse fibrous.

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* *Mineral Industry*, 1902, p. 570.

† *Mineral Resources*, 1902, p. 898.

In dry countries it occurs as a fibrous efflorescence. It is liable to absorb moisture and becomes damp, especially when containing calcium or magnesium chlorides. It is known by its taste.

FIG. 417.

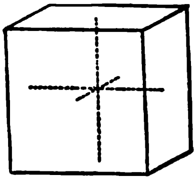
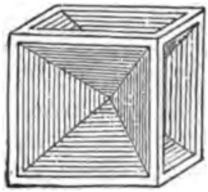


FIG. 418.

FIG. 419.

FIG. 420.



Physical Characters. H., 2.5. Sp. gr., 2.4 to 2.6.

LUSTRE, vitreous. TRANSLUCENT to transparent.

STREAK, white. TENACITY, brittle.

COLOR, white, colorless, yellow, brown, deep blue.

TASTE, salt. CLEAVAGE, cubic.

BEFORE BLOWPIPE, ETC.—Decrepitates violently, fuses very easily and colors the flame yellow and may be volatilized. Easily soluble in cold water.

SIMILAR SPECIES.—The taste distinguishes it from all other minerals.

REMARKS.—Halite occurs with rocks of all ages in beds of great thickness. These are formed by the gradual and complete evaporation of bodies of water into which the salt has been brought in small increments by inflowing streams. Vast lakes and seas of salt water exist in different parts of the world as well as many salt springs.

Innumerable immense deposits of salt are known and worked in almost every civilized country. In the United States we have many deposits. Hundreds of square miles of central and western New York are underlaid by strata of salt varying from a few feet to one or two hundred feet in thickness. Immense amounts of salt are also produced in the Saginaw district of Michigan. At Petite Anse, La., salt is found of such purity and so near the surface that it is simply blasted out and crushed to make it ready for the table. The supply seems to be inexhaustible. In the southeastern part of Nevada a large mountain consists mainly of salt. Many other States also produce this substance, notably, Kansas, West Virginia, Ohio, and California.

The associates are other minerals produced in the same manner, as gypsum, anhydrite and various soluble chlorides, bromides and sulphates.

USES. — Halite is used in immense quantities in food and as a preservative. It is the source of most of the sodium, sodium carbonate, and other sodium compounds of commerce. It is used to glaze pottery, in glass and soap making, and in many metallurgical processes.

MIRABILITE. — Glauber Salt.

COMPOSITION. — $Na_2SO_4 + 10H_2O$ (Na_2O 19.3, SO_3 24.8, H_2O 55.9 per cent.).

GENERAL DESCRIPTION. — Translucent, white, fibrous crusts or monoclinic crystals, closely resembling those of pyroxene in form and angle. On exposure loses water and falls to powder.

Physical Characters. H., 1.5 to 2. Sp. gr., 1.48.

LUSTRE, vitreous. TRANSPARENT to opaque.
STREAK, white. TASTE, salty and bitter.
COLOR, white or faintly greenish.

BEFORE BLOWPIPE, ETC. — On charcoal fuses, colors the flame yellow and leaves a mass which will stain bright silver. In closed tube yields much water. Easily soluble in water.

REMARKS. — Deposits known as "lakes" occur near Laramie, Wyoming, consisting of mud mixed with crystals of mirabilite to a depth of 20 feet. Mirabilite separates also from the Great Salt Lake, Utah, and is heaped up on the shore whenever the temperature falls below a certain point, to be again dissolved in the summer. Found also at the bottom of the Bay of Kara, Caspian Sea.

Thenardite. — Na_2SO_4. Twinned tabular orthorhombic crystals and as an efflorescence. Soluble in water. Found at Borax Lake, Cal., and in alkali lands.

Glauberite. — $Na_2SO_4.CaSO_4$. Tabular monclinic crystals and lamellar masses in rock salt and in the mud of borax lakes.

SODA NITRE.—Chili Saltpetre.

COMPOSITION.—$NaNO_3$, (Na_2O 36.5, N_2O_5 63.5 per cent.).

GENERAL DESCRIPTION.—Rather sectile granular masses or crusts of white color, occurring in enormous beds and as an efflorescence. Rarely found as rhombohedral crystals of the forms of calcite. On exposure crumbles to powder.

Physical Characters. H., 1.5 to 2. Sp. gr., 2.24 to 2.29.

LUSTRE, vitreous. TRANSPARENT.
STREAK, white. TENACITY, brittle.
COLOR, colorless, white or yellowish. TASTE, cooling and salty.

BEFORE BLOWPIPE, ETC.—On charcoal deflagrates less violently than nitre and becomes liquid. Colors the flame yellow. Very easily soluble in water.

REMARKS. — It is associated with salt, gypsum, and many soluble salts. There is only one producing locality, the celebrated nitrate fields of northern Chili. These fields, however, form one of the greatest sources of wealth to that nation. Large deposits are known to exist in Death Valley, Cal., and smaller deposits exist in Nevada and New Mexico.

USES.—It is used in manufacture of nitre and nitric acid in large amounts, and also in fertilizers. It frequently contains sodium iodate and is the chief source of the iodine of commerce.

TRONA.—Urao.

COMPOSITION.—$Na_2CO_3 \cdot NaHCO_3 + 2H_2O$, ($Na_2O$ 41.2, CO_2 38.9, H_2O 19.9.).

GENERAL DESCRIPTION.—Beds and thin crusts of white glistening material, often fibrous and occasionally in monoclinic crystals. It is not altered in dry air.

PHYSICAL CHARACTERS.—Translucent. Lustre, vitreous, glistening. Color, white, gray, yellowish. Streak, white. H, 2.5 to 3. Sp. gr., 2 11 to 2.14. Taste, alkaline.

BEFORE BLOWPIPE, ETC.—Fuses easily, coloring flame yellow. In closed tube yields water and carbon dioxide. Easily soluble in water. Effervesces vigorously in cold dilute acids.

Gay-Lussite. — $Na_2CO_3.CaCO_3.5H_2O$. White monoclinic pyramidal crystals at Soda Lake, Nevada; Venezuela, etc.

THE LITHIUM MINERALS.

The minerals described are:

Phosphate	*Amblygonite*	$Li(Al.F)PO_4$,	Triclinic
Silicates	**Spodumene**	$LiAl(SiO_3)_2$,	Monoclinic
	Lepidolite	$R_3Al(SiO_3)_3$	Monoclinic

The metal lithium is comparatively rare in minerals but is quite easily detected by its very characteristic line in the red of the spectrum. Its salts are of importance in medicine, in the laboratory, and in the preparations of lithia waters. Effervescent lithia tablets are an effective remedy for rheumatism.

Large deposits of the lithium minerals occur at Pala, California, and all the species mentioned above occur there. Spodumene has also been mined in the Black Hills of South Dakota. Amblygonite is also produced at Montebras, France. In 1902 the amount of lithium minerals mined in this country was 1,245 tons* and about 55,000 pounds of lithium salts were consumed of which approximately one third was imported.

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* *Mineral Resources of U. S.*, 1902, p. 261.

AMBLYGONITE.

COMPOSITION. — $Li(Al.F)PO_4$, (Li_2O 10.1 per cent. generally partly replaced).

GENERAL DESCRIPTION. — A cleavable compact massive or columnar mineral somewhat resembling orthoclase. Sometimes in large indistinct crystals.

PHYSICAL CHARACTERS. — H = 6, Sp. Gr. = 3.01–3.09. Lustre, pearly to vitreous. Streak, white. Brittle. Translucent. Color, usually white, sometimes with green, blue, yellow or brown tints.

BEFORE THE BLOWPIPE, ETC. — Gives characteristic red lithia flame, fuses with intumescence to an opaque white globule. Soluble in sulphuric acid when powdered.

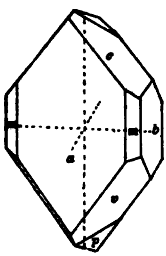
REMARKS. — Occurs in quantity at Pala, California.

USES. — Is an important source of lithium and carries a comparatively high percentage of this element.

SPODUMENE.

COMPOSITION.— $LiAl(SiO_3)_2$, Li_2O 8.4 per cent. with some sodium replacing lithium.

FIG. 421.



GENERAL DESCRIPTION. — White or greenish-white monoclinic crystals, sometimes of enormous size, more rarely small emerald-green, and larger lilac colored crystals. Also in masses. Characterized by an easy parting parallel *a* in addition to the prismatic cleavage.

CRYSTALLIZATION. — Monoclinic. Axes $\grave{a} : \bar{b} : \dot{c} = 1.124 : 1 : 0.636$; $\beta = 69° 40'$ Common. forms: the pinacoids *a* and *b*, the unit prism, *m*, unit pyramid *p*, the pyramid $v = (\grave{a} : \bar{b} : 2c)$; {221} and the clinodome $e = (\infty \grave{a} : \bar{b} : 2c)$; {021}. Supplement angles: $mm = 93°$; $pp = 63° 31'$; $vv = 88° 34'$; $ee = 107° 24'$. Optically +. Axial plane *b*.

Physical Characters. H., 6.5 to 7. Sp. gr., 3.13 to 3.20.

LUSTRE, vitreous. TRANSPARENT to opaque.

STREAK, white. TENACITY, brittle.

COLOR, white, pale-green, emerald, green, pink, purple.

BEFORE BLOWPIPE, ETC.—Becomes opaque, intumesces, swells and fuses to a white or colorless glass, coloring the flame purple-red, especially with hydrochloric acid. Insoluble in acids.

SIMILAR SPECIES.—Distinguished by its tendency to split into thin pearly plates and by the red flame.

REMARKS.—Occurs in granitic rocks with garnet, tourmaline and the granite minerals, quartz, feldspars and micas. It alters readily to a mechanical mixture of albite and mica. Important localities are Stony Point, N. C.; Chesterfield and Huntington, Mass.; Branchville, Conn.; Pennington County, S. D., Pala, Cal., etc.

VARIETIES.

Hiddenite. — Small transparent emerald-green crystals from Alexander Co., N. C.

Kunzite. — A transparent lilac colored spodumene found only at Pala, Cal.

ALTERATIONS. — Spodumene alters to *β spodumene* by replacement of half of Li_2O by Na_2O and by further alteration forms *cymatolite*, a mixture of albite and muscovite.

USES. — The large crystals from the Etta tin mines, South Dakota, are mined as a source of lithium salts. The varieties hiddenite and kunzite are used as gems and the latter is especially valued for its intense phosphorescent properties when exposed to x-rays, ultra-violet light and radium emanations.

LEPIDOLITE. — Lithia Mica.

COMPOSITION. — $R_3Al(SiO_3)_3$. R = Li, K, NaF, etc. Li_2O, 4 to 6 per cent.

GENERAL DESCRIPTION. — Scaly, granular masses of pale-pink color and gray transparent crystals, with easy cleavage into elastic plates.

PHYSICAL CHARACTERS. — Translucent. Lustre, pearly. Color, rose, violet, lilac, gray, white. Streak, white. H., 2.5 to 4. Sp. gr., 2.8 to 2.9. Sectile. Cleavage, basal.

BEFORE BLOWPIPE, ETC. — Fuses easily to a white glass. Colors the flame purple-red. Partially soluble in hydrochloric acid.

REMARKS. — Found in considerable quantity near Pala, San Diego Co., California, with red tourmaline, also at Paris and Hebron, Me., Chesterfield, Mass., Rozena, Moravia, Utö, Sweden, and elsewhere.

USES. — It is a source of lithium salts.

THE AMMONIUM MINERALS.

The minerals described are :

Chloride	*Sal Ammoniac*	NH_4Cl	Isometric
Sulphate	*Mascagnite*	$(NH_4)_2SO_4$	Orthorhombic

The hypothetical compound radical ammonium, has never been separated from its compounds. Its occurrence in nature is rare, and its minerals while of great theoretical interest do not occur in commercial quantities. Its compounds, many of which are of great importance in the arts, are obtained by the dry distillation of organic matter, and notably of bituminous coal in the process of gas manufacture, from coke ovens, from the dry distillation of bones and from the gases of blast furnaces using coal as fuel.

SAL AMMONIAC.

COMPOSITION.—NH_4Cl, (NH_4 33.7, Cl 66.3 per cent.).

PHYSICAL CHARACTERS.—Transparent to translucent. Lustre, vitreous. Color, colorless, white, yellowish. Streak, white. H., 1.5 to 2. Sp. gr., 1.53. Taste, pungent, salt. Cleavage, parallel to octahedron.

BEFORE BLOWPIPE, ETC.—Sublimes, without fusion, as white fumes. With soda or quicklime, gives odor of ammouia. Easily soluble in water.

REMARKS.—Occurs near volcanoes, burning coal-beds and in guano deposits. Artificially, it is a by-product from gas-works.

MASCAGNITE.

COMPOSITION.—$(NH_4)_2SO_4$, ($(NH_4)_2O$ 39.4, SO_3 60 6 per cent.).

GENERAL DESCRIPTION.—Yellowish, mealy incrustations on lava or in guano. Rarely in orthorhombic crystals.

PHYSICAL CHARACTERS.—Translucent. Lustre, dull or vitreous. Color, lemon-yellow, yellowish or gray. Streak, white. H., 2 to 2.5. Sp. gr., 1.76 to 1.77. Taste, pungent and bitter.

BEFORE BLOWPIPE, ETC.—Sublimes without fusion. With soda or quicklime, yields odor of ammonia. Easily soluble in water.

REMARKS.—Occurs on lava or guano or near burning coal-beds. It is artificially made from the ammoniacal liquors of gas-works, coke-ovens, and blast furnaces and to a less extent is a by product from the manufacture of boric acid in Tuscany.

CHAPTER XXXII.

BARIUM AND STRONTIUM MINERALS.

THE BARIUM MINERALS.

THE minerals described are:

Sulphate	**Barite**	$BaSO_4$	Orthorhombic
Carbonate	**Witherite**	$BaCO_3$	Orthorhombic

The metal occurs also in a few silicates.

In the elementary state barium is unimportant. It may be prepared by the electrolysis of its chloride. The only important mineral compound is the sulphate, which is used as an ~~adulterant~~ ingredient in paint. lithopone The mineral is crushed coarsely, treated with sulphuric acid to remove impurities, washed, pulverized and either mixed with white lead or used for giving weight and glaze to paper. Nearly 60,000 tons were mined in this country in 1902. The carbonate is used in sugar refining.

BARITE.—Heavy Spar.

COMPOSITION.—$BaSO_4$, (BaO 65.7, SO_3 34.3 per cent.), sometimes with some strontia, silica, clay, etc.

GENERAL DESCRIPTION.—A heavy white or light-colored mineral, vitreous in lustre. It occurs in orthorhombic crystals, which are frequently united by their broader sides in crested divergent groups, and varying insensibly from this to masses made up of curved or straight lamellæ and cleavable into rhombic plates. It occurs also granular, fibrous, earthy, stalactitic and nodular.

FIG. 422.

FIG. 423.

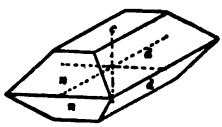


FIG. 424.

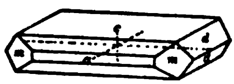
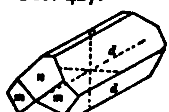


FIG. 425.

FIG. 426.

FIG. 427.



CRYSTALLIZATION. — Orthorhombic. Axes $\breve{a} : \bar{b} : c = 0.815 : 1 : 1.314$.

Unit prism m, base c and domes $d = (\infty\breve{a} : \bar{b} : c)$; {011} and $n = (\breve{a} : \infty\bar{b} : \frac{1}{2}c)$; {102} are the most common forms. Supplement angles are $mm = 78° 23'$; $cd = 52° 43'$; $cn = 38° 52'$.

Optically +. The axial plane parallel b and the acute bisectrix normal to a. Axial angle with yellow light $2E = 63° 12'$.

Physical Characters. H., 2.5 to 3.5. Sp. gr., 4.3 to 4.6.
LUSTRE, vitreous and pearly. TRANSPARENT to opaque.
STREAK, white. TENACITY, brittle.
COLOR, white or light shades of yellow, brown, red or blue.
CLEAVAGE, basal and prismatic (101° 37′ being prism angle).

BEFORE BLOWPIPE, ETC—In forceps, decrepitates and fuses, coloring the flame yellowish-green and leaving an alkaline residue. With soda, on charcoal, gives sulphur reaction. Insoluble in acids.

SIMILAR SPECIES.—Distinguished among non-metallic minerals by its high specific gravity, insolubility and green flame.

REMARKS. — Frequently found in veins and beds, with ores of antimony, lead, copper, iron, etc.; also as veins and masses in limestones. The important American localities producing barite are Madison and Gaston Counties, N. C., Richlands, Va., and Washington Co., Mo. Tennessee, Connecticut, Kentucky and Illinois also have extensive deposits. Some barite is also imported from abroad, Germany and Hungary both have important mines.

USES. — The white variety is ground and used as an adulterant of white lead and for weighting paper. Colored varieties are sometimes cut into paper weights, vases, etc. Barite is also made into barium chloride and hydrate.

WITHERITE.

FIG. 428.

Cumberland, Eng.

COMPOSITION. — $BaCO_3$ (BaO 77.7, CO_2 22.3 per cent.).

GENERAL DESCRIPTION. — Heavy white or gray translucent masses of vitreous lustre, sometimes with small indistinct crystals or globular or botryoidal groups. Also granular, columnar and in crystals resembling those of quartz.

CRYSTALLIZATION. — Orthorhombic. Axes

$\breve{a} : \bar{b} : \acute{c} = 0.603 : 1 : 0.730$. Crystals always repeated twins resembling hexagonal pyramids with usually horizontal striations or deep grooves on the faces, Fig. 428. Optically —.

Physical Characters. H., 3 to 4. Sp. gr., 4.29 to 4.35.

LUSTRE, vitreous. TRANSLUCENT.

STREAK, white. TENACITY, brittle.

COLOR, white, gray, yellowish.

BEFORE BLOWPIPE, ETC.—Fuses rather easily, coloring flame yellowish-green and becoming alkaline. Soluble in dilute hydrochloric acid, with effervescence, and less rapidly soluble in strong acid.

SIMILAR SPECIES.—Distinguished by its weight, effervescence with acids and green flame.

REMARKS.—Occurs in veins with lead ores or with ores of silver or barite, and is probably deposited from solution in water containing carbonic acid. Witherite is not mined in the United States, although small deposits occur near Lexington, Ky., and on the north shore of Lake Superior. The most productive mines are at Fallowfield in England.

USES. — As an adulterant of white lead and in refining beet-sugar molasses.

Barytocalcite. — $BaCa(CO_3)_2$. Monoclinic needles and masses of yellowish-white color found in the witherite locality. Always yields a weak manganese test.

THE STRONTIUM MINERALS.

The minerals described are:

Carbonate	**Strontianite**	$SrCO_3$	Orthorhombic
Sulphate	**Celestite**	$SrSO_4$	Orthorhombic

The strontium minerals are chiefly of use to form strontium salts used as precipitants of sugar from the molasses residues of the beet sugar industry, and in the manufacture of the nitrate for use in the red fire of fire works.

CELESTITE.

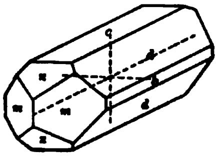
COMPOSITION—$SrSO_4$. (SrO 56.4, SO_3 43.6 per cent.).

GENERAL DESCRIPTION.—A white translucent mineral, often with a faint bluish tinge. Occurs in tabular to prismatic orthorhombic crystals, fibrous and cleavable masses, and rarely granular. It is notably heavy, and has a general resemblance to barite.

CRYSTALLIZATION. — Orthorhombic. Axes $\breve{a} : \bar{b} : c = 0.779 : 1 : 1.280$.

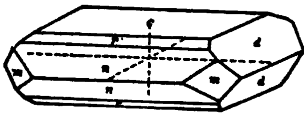
The common forms are the base c, the unit prism m and the domes n and o. The supplement angles are $mm = 75° 50'$; $cn = 39° 25'$; $co = 52°$.

FIG. 429.



Sicily.

FIG. 430.



Lake Erie.

Optically +. Axial plane b. Acute bisectrix normal to a. Axial angle with yellow light $2E = 88° 38'$.

Physical Characters. H., 3 to 3.5. Sp. gr., 3.95 to 3.97.

LUSTRE, vitreous or pearly. TRANSPARENT, nearly opaque.

STREAK, white. TENACITY, brittle.

COLOR, white colorless, pale blue or reddish.

CLEAVAGE.—Basal and prismatic, yielding rhombic plates in which the rhomb angles are 104° 10′ and 75° 50′.

BEFORE BLOWPIPE, ETC.—Fuses easily to a white pearly glass and colors the flame crimson. Usually decrepitates and becomes alkaline. With soda on charcoal gives sulphur reaction. Insoluble in acids.

SIMILAR SPECIES.—Distinguished from barite by its red flame and from other minerals by its high specific gravity, insolubility and red flame.

REMARKS.—Celestite occurs frequently in cavities in limestone, marl or sandstone or with beds of gypsum or in volcanic regions with sulphur, gypsum, etc. The island of Sicily contains the most celebrated deposits of this mineral, and is the chief producing locality. In the United States deposits occur on Strontian and N. Bass Island, Lake Erie, at Bell's Mills, Pa., at Chaumont Bay, Lockport, and other places in western New York. In Kansas, Texas, West Virginia and Tennessee, also at Kingston, Canada.

USES.—It is a source of strontium nitrate used to make crimson color in fireworks.

STRONTIANITE.

COMPOSITION.—$SrCO_3$, (SrO 70.1, CO_2 29.9 per cent.).

GENERAL DESCRIPTION.—Usually found as yellowish-white or greenish-white masses made of radiating imperfect needle crystals and spear-shaped crystals, very like those of aragonite. Also fibrous or granular and only rarely in distinct orthorhombic crystals, sometimes of considerable size.

Physical Characters. H., 3 to 3.5 Sp. gr., 3.68 to 3.72.

LUSTRE, vitreous. TRANSLUCENT.

STREAK, white. TENACITY, brittle.

COLOR, pale yellowish or greenish-white, also green, gray and colorless.

BEFORE BLOWPIPE, ETC.—In forceps swells, sprouts, colors the flame crimson, fuses on the edges and becoming alkaline. Soluble in cold dilute acids with effervescence.

SIMILAR SPECIES.—Differs from calcite and aragonite in fusibility, higher specific gravity and purer red flame. The flame and effervescence distinguish it from all other minerals.

REMARKS.—Strontianite is found in the United States chiefly in the State of New York, especially at Schoharie, Muscalonge Lake, Chaumont Bay, Theresa and Clinton. Strontianite used in the German beet sugar industry is largely obtained from Westphalia.

USES.—It is the chief source of the strontium salts used in fireworks, and is also converted into the hydroxide and used to precipitate sugar from molasses as a strontium compound from which crystalline sugar can later be obtained.

CHAPTER XXXIII.

CALCIUM AND MAGNESIUM MINERALS.

THE CALCIUM MINERALS.

THE minerals described are:

Fluoride	**Fluorite**	CaF_2	Isometric
Sulphates	**Anhydrite**	$CaSO_4$	Orthorhombic
	Gypsum	$CaSO_4 + 2H_2O$	Monoclinic
Phosphate	**Apatite**	$Ca_5(Cl.F)(PO_2)_3$	Hexagonal
Carbonates	**Aragonite**	$CaCO_3$	Orthorhombic
	Calcite	$CaCO_3$	Hexagonal
	Dolomite	$CaCO_3.MgCO_3$	Hexagonal
	Ankerite	$(Ca.Mg.Fe)CO_3$	Hexagonal
Tungstate	**Scheelite**	$CaWO_4$	Tetragonal

Massive CALCITE and DOLOMITE, that is limestone and marble, are quarried in enormous quantities, the production of limestone exceeding in value even that of granite.

In 1902 there was produced in this country * \$5,044,182 worth of marble, while of limestone the value was: for building, \$5,563,084; as lime, \$9,335,618; for roads, \$2,890,985; for railroad ballast, \$2,661,081; for flux, 12,139,248 tons valued at \$5,271,252, and for other purposes, \$4,508,983.

In addition to the uses enumerated above, limestone is used for hydraulic cements, and in 1903 † 8,200,000 barrels of natural hydraulic cement and 19,000,000 barrels of Portland cement were produced in the United States.

GYPSUM to the amount of 816,478 tons ‡ was mined in this country in 1902, of which about three quarters was burned to produce plaster of Paris and wall plaster, and the remainder was either ground and used as land plaster or sold in the crude state. There has been a greatly increased output of gypsum mainly from the growing use of the calcined product as wall plaster in modern buildings and from a recent use of ground selenite with wood pulp

* *Mineral Resources*, 1902, p. 698.

† *Engineering and Mining Journal*, 1904, p. 4.

‡ *Mineral Resources*, 1902, p. 903.

in paper making. About 3,000 tons are also used for bedding plate glass during the grinding process.

APATITE and phosphate rock are used in enormous quantities for the manufacture of soluble phosphates for fertilizers. Florida, South Carolina and Tennessee produced 1,477,601 long tons of phosphate rock * in 1903. The phosphoric acid is rendered available for the use of plants by treating the rock with sulphuric acid.

FLUORITE has an increasing use as a flux in melting iron and other metallurgical operations. It is also used in producing opalescent glass and enamels and in the manufacture of hydrofluoric acid. In 1902 † 48,108 tons were mined in the United States mainly from Kentucky and Illinois.

FLUORITE. — Fluor Spar.

COMPOSITION.—CaF_2, (Ca 51.1, F 48.9 per cent.).

GENERAL DESCRIPTION.—Usually found in glassy transparent cubes or cleavable masses of some decided yellow, green, purple or violet color. Less frequently granular or fibrous. Massive varieties are often banded in zigzag strips of different colors.

FIG. 431.

Fluorite, Cumberland, England. N. Y. State Museum.

* *Engineering and Mining Journal*, 1904, p. 4.
† *Mineral Resources of the U. S.*, 1902, p. 899.

CRYSTALLIZATION. — Isometric. Usually cubes with modifying forms, especially the tetrahexahedron $e = (a : 2a : \infty a)$, $\{210\}$; the dodecahedron d and the hexoctahedron $t = (a : 2a : 4a)$, $\{421\}$. The cube faces are often striated parallel to the edges or with vicinal faces, p. 132, giving the appearance of a very flat tetrahexahedron. Rarely found in octahedrons, sometimes formed by

FIG. 432.

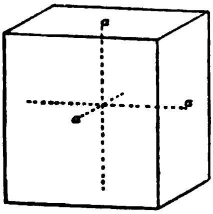


FIG. 433.

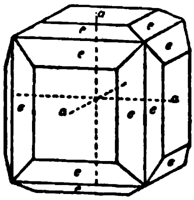
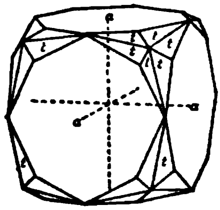


FIG. 434.



the grouping of small cubes in parallel positions. Penetration twins common, Fig. 431.

Index of refraction for yellow light 1.4339.

Physical Characters. H., 4. Sp. gr., 3.01 to 3.25.

LUSTRE, vitreous. TRANSPARENT to nearly opaque.

STREAK, white. TENACITY, brittle.

COLOR, wine-yellow, green, violet, blue, colorless, brown, black.

CLEAVAGE, octahedral.

BEFORE BLOWPIPE, ETC. — In closed tube at a low heat becomes phosphorescent. In forceps fuses to a white opaque glass and colors the flame red. Soluble in hydrochloric acid. Heated with acid potassium sulphate or sulphuric acid, fumes are set free which corrode glass.

SIMILAR SPECIES.—Recognized by cleavage and crystals and by the etching test. When cut it may resemble aqua marine, yellow topaz, etc., but is distinguished by softness.

REMARKS.—Fluorite may have been deposited from solution in carbonated waters. It is usually found in veins as the gangue of metallic ores, especially lead, silver, copper, and tin. Sometimes found in beds. This mineral is mined in large quantities at Rosiclare, Illinois. Found in smaller amounts in Jefferson and Boulder counties, Colo.; at McComb and other places in western New York. In many localities throughout New England, also in New Jersey, Arizona, Virginia, California and other States.

USES.—It is used as a flux in smelting ores; also in the manufacture of opalescent glass, hydrofluoric acid, enamel for cooking

utensils, and the brighter colored varieties are cut into vases, figures or imitation gems. Used in small amounts as a constituent of the bath used in the electrolytic production of aluminium.

ANHYDRITE.

COMPOSITION.—$CaSO_4$, (CaO 41.2, SO_3 58.8 per cent.).

GENERAL DESCRIPTION.—Granular, marble-like or sugar-like in texture, or as fibrous and lamellar masses of white, gray, bluish or reddish color. Cleavage in three directions at right angles. Rarely in orthorhombic crystals.

Physical Characters. H., 3 to 3.5. Sp. gr., 2.9 to 2.98.

LUSTRE, vitreous or pearly. TRANSLUCENT to opaque.

STREAK, white. TENACITY, brittle.

COLOR, white, gray, bluish, brick-red. CLEAVAGES at right angles.

FIG. 435.

Gypsum, Montmartre, Paris, France. N. Y. State Museum.

BEFORE BLOWPIPE, ETC.—Fuses to a white enamel and colors the flame red. With soda yields a sulphur reaction. Soluble slowly in acids.

SIMILAR SPECIES.—Differs from gypsum in being harder and not yielding decided test for water. Does not effervesce in acids like marble. Cleavage pseudo-cubic.

REMARKS.—Anhydrite occurs with rock salt, limestone, or with gypsum, from which it may have been formed by heat. It changes to gypsum by hydration, often with swelling or efflorescence. The chief American locality is at Hillsboro, New

Brunswick. Also abundant in Nova Scotia. Found in smaller quantity at Lockport, N. Y., in eastern Pennsylvania and in Tennessee.

USES.—A siliceous variety is cut and polished for ornamental work. Its tendency to swell prevents its use in building.

GYPSUM.—Selenite, Alabaster.

COMPOSITION.—$CaSO_4 + 2\,H_2O$, (CaO 32.5, H_2O 20.9, SO_3 46.6 per cent.).

GENERAL DESCRIPTION.—Soft colorless white or slightly tinted masses, which may be granular or compact, or may be translucent and silky, fibrous or transparent and cleavable into plates and strips. Also in transparent cleavable monoclinic crystals.

FIG. 436.

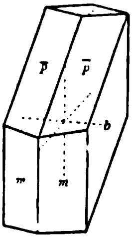


FIG. 437.

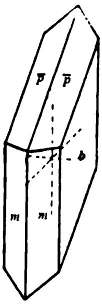


FIG. 438.

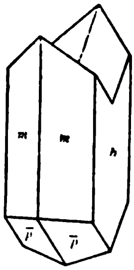
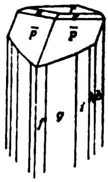


FIG. 439.



Utah.

CRYSTALLIZATION. — Monoclinic. $\beta = 80° \; 42'$. Axes $\breve{a} : \bar{b} : c = 0.690 : 1 : 0.412$.

Frequently the negative unit pyramid $\bar{p}$, with the unit prism m and clino-pinacoid b, Figs. 437 and 440, or these twinned, Fig. 438, or with dome $r = (\breve{a} : \infty \bar{b} : \frac{1}{3}c)$, $\{103\}$; Figs. 436 and 439. Supplement angles $mm = 68° \; 30'$; $\bar{p}\bar{p} = 36° \; 12'$; $cr = 11° \; 29'$.

FIG. 440.

Gypsum, Ellsworth, Ohio. Foote Mineral Co.

Optically $+$. Axial plane at ordinary temperature b, but with higher temperatures the axial angle diminishes and the axes pass into a plane at right angles to b, the axes for red light so passing at about 120° C.,

those for yellow light at about 135° C., and the others each at a definite temperature.

Physical Characters. H., 1.5 to 2. Sp. gr., 2.31 to 2.33.

LUSTRE, pearly, silky, vitreous. TRANSPARENT to opaque.

STREAK, white. TENACITY, brittle, laminæ flexible.

COLOR, white, colorless, gray, red, yellow, brown.

CLEAVAGE, clino-pinacoid perfect, unit ortho-dome fibrous, and ortho-pinacoid conchoidal. The cleavage fragments are rhombic plates with angles 66° and 114°.

BEFORE BLOWPIPE, ETC. — When heated quickly becomes white and opaque and fuses to an alkaline globule, coloring the flame yellowish-red. In closed tube yields water. Soluble in hydrochloric acid. The powdered dehydrated mineral when mixed with water will form a compact mass. Gives sulphur reaction.

VARIETIES.

Selenite.—Crystals or transparent cleavable masses.

Satin Spar.—Fine translucent fibrous varieties with sheen of silk.

Alabaster.—Compact and fine grained, suitable for carving.

Rock Gypsum.—Scaly, granular or dull colored and compact.

SIMILAR SPECIES.—Talc, brucite, mica, calcite, heulandite, stilbite. It is softer than all but talc, lacks the greasy feeling of talc and is further characterized by quiet solubility, cleavages and calcium flame.

REMARKS.—Gypsum occurs in large beds with limestones, marls, and clays, and in volcanic regions with sulphur. It is frequently formed by the action of the sulphuric acid from decomposing sulphides, upon calcareous minerals. It is also formed by the dehydration of anhydrite, by the evaporation of lakes and seas and by the action, in volcanic regions, of sulphurous vapors on limestone.

The largest producing locality in the United States is in the region of Alabaster, Michigan. Other producing localities are Ottawa county, Ohio, Smith and Washington counties, Virginia, Webster county, Iowa, and many places in central and western New York. Deposits of gypsum in quantity are also known at Scottsboro, Ala., Calcasien, La., Royston's Bluff, Ark. Also in Texas, Colorado, Kansas, Montana, Utah and most of the other States and Territories. Large quantities are annually imported from New Brunswick and Nova Scotia. Celebrated deposits also occur in Spain and Sicily.

USES.—When burned and ground it is called plaster-of-Paris. In this state if mixed with water, it becomes hard and sets, is used

for the production of casts, moulds, cements, washes and the hard finish on inside walls of houses.

Land plaster is ground gypsum, and is used on soils. Minor uses are: Satin spar for cheap jewelry, selenite in optical work and alabaster in carving.

APATITE.—Asparagus Stone. Phosphate Rock.

COMPOSITION.—$Ca_5(Cl.F)(PO_4)_3$.

GENERAL DESCRIPTION.—Large and small hexagonal prisms, usually of green or red color, but sometimes violet, white or yellow. Also in compact varieties which are commonly dull-gray or white, rock-like masses or nodules not unlike common limestone.

FIG. 441.

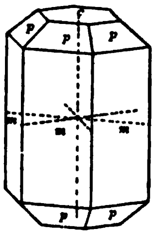


FIG. 442.

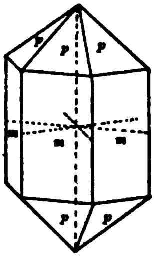


FIG. 443.

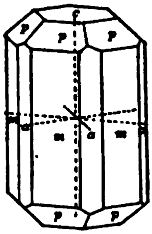


FIG. 444.

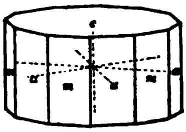
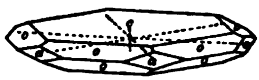
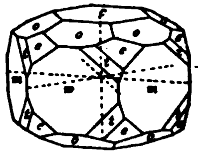


FIG. 445.



Paris, Me.

FIG. 446.



Zillerthal.

CRYSTALLIZATION.—Hexagonal. Class 3° order pyramid, p. 51. Axis $c = 0.735$. Usually the unit prism m terminated by the unit pyramid p with or without the base c. More rarely the second order prism a or the flat pyramid $o = (a : \infty a : a : \frac{1}{2}c)$, $\{10\bar{1}2\}$, Fig. 445; and occasionally third order pyramids, as $t = (\frac{4}{3}a : 4a : a : \frac{4}{3}c)$, $\{31\bar{4}3\}$, Fig. 446.

Supplement angles: $pp = 37° 44'$; $rr = 22° 31'$; $cp = 40° 18'$; $cr = 22° 59'$. Optically —, low refraction, weak double refraction.

Physical Characters. H., 4.5 to 5. Sp. gr., 3.17 to 3.23.

LUSTRE, vitreous to resinous. TRANSPARENT to opaque.

STREAK, white. TENACITY, brittle.

COLOR, green, red, brown, yellow, violet, white, colorless.

CLEAVAGE, imperfect basal and prismatic.

BEFORE BLOWPIPE, ETC.—Fuses with difficulty on sharp edges and colors the flame yellowish-red, or, if moistened with concentrated sulphuric acid, colors the flame momentarily bluish-green. Easily soluble in hydrochloric acid.

If to ammonium molybdate in nitric acid solution a few drops of a nitric acid solution of apatite be added, a bright-yellow precipitate will be thrown down on heating. In the chlorine variety silver nitrate will produce a curdy white precipitate in the nitric acid solution.

VARIETIES.—Certain mineral deposits are essentially of the same composition as crystalline apatite.

Phosphorite.—Concretionary masses, with fibrous or scaly structure. $H = 4.5$.

Osteolite.—Compact, earthy, impure material, of white or gray color. H., 1 to 2.

Phosphate Rock or Nodules.—The former in place of original deposition, the latter chiefly in river beds. Massive, gray, white, brown or black. H., 2 to 5.

Guano.—Granular to sponge-like and compact material, of gray to brown color. Sometimes with lamellar structure.

SIMILAR SPECIES.—Green crystals, differ from beryl in lustre, hardness and solubility. Red crystals differ from willemite in not gelatinizing or yielding zinc.

REMARKS.—Occurs in granites, limestones, tin veins, beds of iron ore, etc., frequently as inclusions in other minerals, and is of both igneous and secondary origin. The most productive American localities for the pure mineral are in Ontario and Quebec, Canada; Ottawa County, Quebec, having several productive mines. Other deposits, but smaller in extent, occur at Bolton, Mass.; Crown Point, N. Y., and Hurdstown, N. J. Immense deposits of the phosphate rock, so largely used in fertilizers, occur in eastern South Carolina and in Florida; in the latter case underlying a wide belt of country and extending through several counties in the central part of the State.

USES.—The massive varieties and some crystalline deposits furnish most of the phosphates for fertilizers. It is converted into soluble phosphates by treatment with sulphuric acid, in which state it is available as plant food. Apatite is also used in the manufacture of phosphorus.

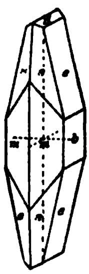
Pharmacolite.—$CaHAsO_4.2H_2O$. White or pink silky fibers or powders. Yields garlic odor when heated. Occurs with arsenical ores.

ARAGONITE. — Flos Ferri.

COMPOSITION. — $CaCO_3$, (CaO 56.0, CO_2 44.0 per cent.).

GENERAL DESCRIPTION. — This form of calcium carbonate is found in orthorhombic crystals, which are frequently pseudo-hexagonal from twinning, and as groups of acutely terminated needle crystals, which grade into fine fibers. It also occurs stalactitic, incrusting and in pure white groups of interlacing, coral-like stems. The prevailing tint is white, but the color is occasionally violet or pale green.

FIG. 447.



Bilin, Bohemia.

FIG. 448.

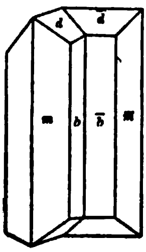
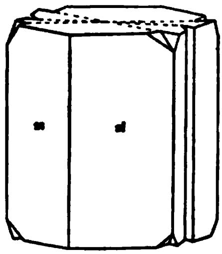
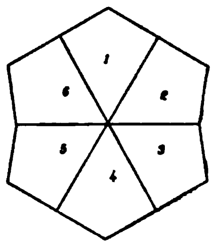


FIG. 449.



Herrengrund.

FIG. 450.



CRYSTALLIZATION. — Orthorhombic. Axes $\breve{a} : \bar{b} : c = 0.622 : 1 : 0.721$. Occasionally simple crystals, Fig. 447, with acute domes and pyramids such as $c = (\infty \breve{a} : \bar{b} : 6c)$, $\{061\}$; and $s = (\frac{4}{3}\breve{a} : \bar{b} : 6c)$, $\{9.12.2\}$. These grade into needle-like forms. More frequently twinned, with twin plane m, giving prisms with pseudo-hexagonal cross sections, Figs. 449 and 450.

Supplement angles are: $mm = 63° \ 48'$; $dd = 71° \ 33'$; $vv = 130° \ 21'$.

Optically —. Axial plane a. Acute bisectrix normal to c. Axial angle for yellow light, $2E = 30° \ 54'$.

Physical Characters. H., 3.5 to 4. Sp. gr., 2.93 to 2.95.

LUSTRE, vitreous. TRANSLUCENT or transparent.

STREAK, white. TENACITY, brittle.

COLOR, white, violet, yellow, pale green.

CLEAVAGE.—Parallel to brachy pinacoid, prism, and brachy dome.

BEFORE BLOWPIPE, ETC.—Infusible, colors flame red. In closed tube decrepitates, loses weight and falls to pieces. With hydrochloric acid, dissolves with rapid effervescence. Powdered and boiled in a test-tube with dilute cobalt solution aragonite is turned to a lilac color.

SIMILAR SPECIES.— Natrolite and other zeolites which occur in needle crystals do not effervesce in acids. Strontianite and witherite have higher specific gravity and are fusible. Calcite has a lower specific gravity, differs in form, cleaves in three directions with equal ease yielding a rhombohedron of 105° 5′, and in powder is unaffected when boiled with cobalt solution.

REMARKS.—Aragonite is largely deposited from carbonated water solution principally in rock cavities and mineral veins. It is found with gypsum and in beds of serpentine and with iron ores as flos ferri, the coraloidal variety.

It can be changed into calcite by heat, and the difference between it and calcite is supposed to be that the calcite is deposited from cold solution and aragonite from hot solution. It is not of common occurrence, but is found at Sulphur Creek and Colton, California, also in Solano County, Cal.; in Lockport and Edenville, N. Y.; in Madison County, N. Y.; Haddam, Ct.: Warsaw, Ill., etc.

CALCITE.—Calcspar, Limestone, Marble, Iceland Spar, Etc.

COMPOSITION.—$CaCO_3$, (CaO 56.0, CO_2 44.0 per cent.).

GENERAL DESCRIPTION.—Yellowish white to white or colorless, more or less transparent crystals, usually rhombohedrons or scalenohedrons. Massive with easy cleavage or coarse to fine-grained, stalactitic, and occasionally fibrous, lamellar or pulverulent.

CRYSTALLIZATION. — Hexagonal. Scalenohedral class, p. 42. Axis $c = 0.854$.

Occurs in many forms, of which the most common are the rhombohedra: p, the unit; $e = (a : \infty a : a : \frac{1}{2}c)$, $\{10\bar{1}2\}$; $f = (a : \infty a : a : 2c)$, $\{20\bar{2}1\}$; $q = (a : \infty a : a : 16c)$, $\{16.0.\overline{16}.1\}$; the scalenohedron: $v = \frac{3}{2}a : 3a : a : 3c$, and the unit prism. Twins are frequent. Supplement angles are $pp = 74° 55'$; $ee = 45° 3'$; $ff = 101° 9'$; $qq = 119° 24'$. The polar edges vv are $75° 22'$ and $35° 36'$.

Optically —. With very strong double refraction, but weak refraction ($\alpha = 1.486$; $\gamma = 1.658$ for yellow light).

Physical Characters. H., 3. Sp. gr., 2.71 to 2.72.

LUSTRE, vitreous to dull. TRANSPARENT to opaque.

STREAK, white. TENACITY, brittle.

COLOR, yellow, white, colorless, or pale shades of red, green, blue, etc.

FIG. 451.

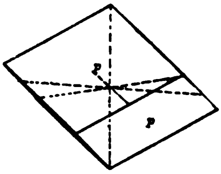


FIG. 452.

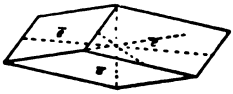


FIG. 453.

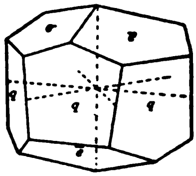


FIG. 454.

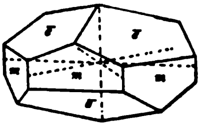


FIG. 455.

Dog Tooth Spar, Geikie.

FIG. 456.

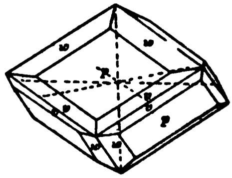


FIG. 457.

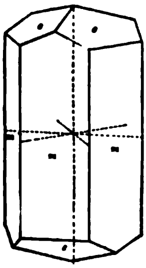


FIG. 458.

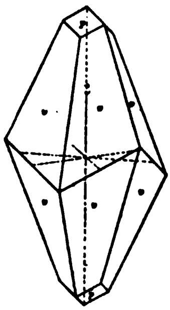


FIG. 459.

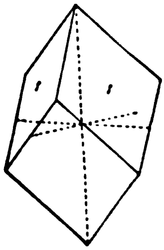


FIG. 460.

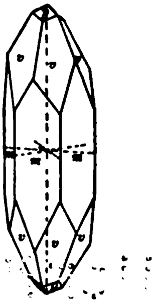


FIG. 461.

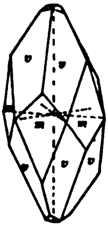


FIG. 462.

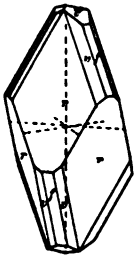
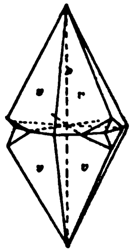


FIG. 463.



CLEAVAGE, parallel to the rhombohedron, therefore yielding diedral angles of 105° 5′ and 74° 55′.

BEFORE BLOWPIPE, ETC.—Infusible. Becomes opaque and alkaline and colors flame red. Soluble readily in cold dilute acids, with vigorous effervescence.

VARIETIES.—The following are the most prominent varieties:

Iceland Spar.—Colorless, transparent crystals and masses.

Dog Tooth Spar.—Scalenohedral crystals, supposed to resemble canine teeth in shape.

Fontainebleau Sandstone.—Crystals containing up to 60 per cent. of sand.

Satin Spar.—Fibrous, with silky lustre.

Argentine.—Foliated, pearly masses.

Marble.—Coarse to fine granular masses, crystalline.

Limestone.—Dull, compact material, not composed of crystalline grains.

Chalk.—Soft, dull-white, earthy masses.

Calcareous Marl.—Soft, earthy and intermixed with clay.

Stalactites.—Icicle-like cylinders and cones, formed by partial evaporation of dripping water.

Stalagmite.—The material forming under the drip on the floor of the cavern.

Travertine, Onyx.—Deposits from springs or rivers, in banded layers.

Other names, such as *Hydraulic Limestone*, *Lithographic Limestone*, *Rock Meal*, *Plumbocalcite*, *Spartaite*, etc., are of minor importance, and are chiefly based on color, use, locality, etc., and do not generally indicate important structural or chemical differences.

SIMILAR SPECIES.—The distinctions from aragonite have been given under that mineral. Dolomite differs in slow partial solution in cold dilute acids, instead of rapid and complete effervescence.

REMARKS.—Calcite is very widely distributed. It is derived, in great part, from fossil remains, shells, corals, etc, but also, in considerable part, by the decomposition of calcium silicates by hot carbonated waters, and possibly, in a degree, by the action of heat on aragonite. The carbonated waters deposit aragonite or calcite, according to the temperature of the solution. In the production of marble Vermont is far ahead of any other State, and the centre of the industry is situated at Rutland. Georgia and Tennessee also produce large quantities, especially of a beautiful, coarse, granular structure. Alabama, California, New York, Pennsylvania and Massachusetts also

have large deposits, some of which are worked. Crystallized calcite occurs throughout the world in all limestone regions. In the United States these localities are innumerable and transparent varieties are common. Rossie, N. Y.; Warsaw, Ill., and Llano and Lampasas Counties, Texas, may be especially noteworthy. Fine stalactites occur in the caves of Virginia, Kentucky and New York. Deposits from thermal springs are common in the Yellowstone Park, and similar deposits occurring in San Luis Obispo County, California, are cut and polished, yielding slabs of onyx marble of extreme beauty.

USES.—Limestone and marble are important building stones, and the latter is also used for statuary, ornaments, interior work, tombstones, etc. Limestone, again, is used for making quicklime and as a flux in smelting siliceous ore, in glass-making, in many chemical processes, in hydraulic cement, as a lithographic stone for playing marbles, etc. Iceland spar is used in optical apparatus for polarizing light.

DOLOMITE.—Pearl Spar, Magnesian Limestone.

COMPOSITION. — $CaCO_3.MgCO_3$ often contains iron or manganese.

GENERAL DESCRIPTION.—Small, white, pink or yellow, rhombohedral crystals, usually with curved faces, or more frequently white, massive marble, with coarse to fine grain ; or gray, white and bluish, compact limestone.

CRYSTALLIZATION. — Hexagonal, class of third order rhombohedron, p. 48. Axis $\dot{c} = 0.832$. Usually the unit rhombohedron

FIG. 464.

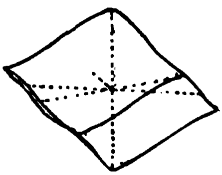
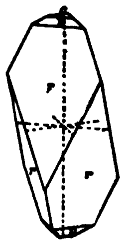


FIG. 465.



p, Fig. 464, the faces curved or doubly curved (saddle-shaped). Often made up of smaller crystals. Sometimes the more acute rhombohedron $r = (a : \infty a : a : 4c)$, $\{40\bar{4}1\}$. Supplement angles are $pp = 73° \ 45'$; $rr = 113° \ 53'$.

Optically —, with even stronger double refraction than calcite.

Physical Characters. H., 3.5 to 4. Sp. gr., 2.8 to 2.9.
LUSTRE, vitreous or pearly. TRANSLUCENT to opaque.
STREAK, white. TENACITY, brittle.
COLOR, white, pink, greenish-gray, brown or black.
CLEAVAGE. Rhombohedral. Angles, 106° 15′ and 73° 45′.

BEFORE BLOWPIPE, ETC.—Infusible, colors flame yellowish-red and becomes alkaline. With cobalt solution, becomes pink. *Fragments* are very slightly attacked by cold dilute acid. The powdered mineral is sometimes attacked vigorously by cold dilute acid, but sometimes is not. On heating there is a vigorous effervescence.

SIMILAR SPECIES.—Differs from calcite in effervescence, color with cobalt solution and frequent curvature of rhombohedral planes. It differs from siderite and ankerite in not becoming magnetic on heating.

REMARKS.—Dolomite is frequently the chief constituent of whole mountain ranges and may have formed: 1. From a solution of the mixed carbonates of calcium and magnesium in carbonated waters. 2. From calcite by infiltration of waters containing magnesium carbonate. 3. By solution of part of calcium carbonate of a magnesian limestone in preference to the less soluble magnesium carbonate, thus increasing the proportion of the latter. Many of the marbles of Vermont, Georgia and Tennessee contain magnesium, and frequently enough to be classed under dolomite. Crystals are common in many localities, especially in the zinc region of Missouri, in many places in the limestone region of Western New York, in the gorge at Niagara, at Glen Falls and Brewsters, N. Y., at Stony Point, N. C.; Roxbury, Vt., and elsewhere.

USES.—The same as for calcite. The dolomite limestone and marble are less soluble than the calcite varieties, and are to that extent, preferable for construction. It is also used for making epsom salts and as a refractory material for lining converters for the basic steel processes.

ANKERITE.

COMPOSITION.—$(Ca.Mg.Fe)CO_3$ sometimes containing manganese.

GENERAL DESCRIPTION.—Gray to brown rhombohedral crystals like those of siderite, also cleavable and granular masses and compact.

PHYSICAL CHARACTERS.—Translucent to opaque. Lustre, vitreous to pearly. Color, gray, yellow or brown. Streak, white or nearly so. H., 3.5 to 4. Sp. gr., 2.95 to 3.1. Brittle. Cleavage, rhombohedral. $R \wedge R = 106° \ 12'$.

BEFORE BLOWPIPE, ETC.—Infusible, darkens and becomes magnetic. Soluble in acids with effervescence.

SCHEELITE.

COMPOSITION.—$CaWO_4$, (CaO 19.4, WO_3 80.6 per cent.), sometimes with replacement by molybdenum.

GENERAL DESCRIPTION.—Heavy brownish white or white masses and square pyramids. Also drusy crusts of yellow or brown crystals.

FIG. 466.

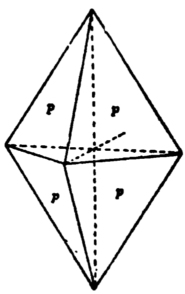
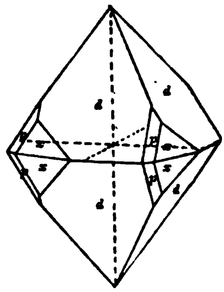
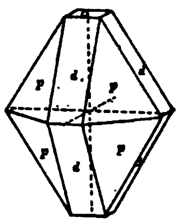


FIG. 467.



Schlackenwald.

FIG. 468.



Trumbull, Conn.

CRYSTALLIZATION. — Tetragonal. Class of third order pyramid, p. 41. Axis $\dot{c} = 1.536$.

The unit first order pyramid p and second order d are most common with sometimes a modifying third order pyramid, $x = (a : 3a : 3c)$, $\{311\}$. Supplement angles are $pp = 79° \, '55$; $ee = 72° \, 40'$.

Optically +.

Physical Characters. H., 4.5 to 5. Sp. gr., 5.4 to 6.1.

LUSTRE, adamantine. TRANSPARENT to opaque.

STREAK, white. TENACITY, brittle.

COLOR, pale yellow, gray, brown, white or green.

CLEAVAGE, distinct parallel to first order pyramid, indistinct parallel to second order pyramid.

BEFORE BLOWPIPE, ETC. — Fusible with difficulty on sharp edges. In salt of phosphorus forms a clear bead which in the reducing flame becomes deep blue, and if the bead is powdered and dissolved in dilute hydrochloric acid it yields a deep blue solution, especially on addition of metallic tin. Scheelite is soluble in hydrochloric or nitric acid, leaving a yellow residue.

SIMILAR SPECIES.—Distinguished among non-metallic minerals by its weight and behavior in salt of phosphorus.

REMARKS.—Scheelite occurs in crystalline rocks, and usually with cassiterite, wolframite, topaz, fluorite, molybdenite, and in quartz. It changes into wolframite, and also forms from wolframite. The mineral is by no means common, but is found at Monroe and Trumbull, Conn.; Flowe mine, S. C., in Nevada, Idaho, and Colorado. Also in large crystals at Marlow, Quebec.

USES.—Scheelite is used as a source of tungsten, which has important properties when used in the manufacture of ferro-tungsten and tungsten steel. Other applications are in the manufacture of tungstic acid, from which a yellow pigment is obtained, and tungstate of soda, which renders fabrics almost incombustible.

THE MAGNESIUM MINERALS.

The minerals described are:

Hydroxide	**Brucite**	$Mg(OH)_2$	Hexagonal
Sulphate	*Epsomite*	$MgSO_4.7H_2O$	Orthorhombic
Carbonate	**Magnesite**	$MgCO_3$	Hexagonal
Aluminate	**Spinel**	$Mg(AlO_2)_2$	Isometric

Magnesia is also the principal base in several important silicates, enstatite, chrysolite, serpentine, talc, etc., and occurs in many others, and in the carbonate dolomite.

Over 50,000 tons of the carbonate, magnesite, are consumed annually in the United States. The hydroxide and sulphate also occur in considerable quantities.

Calcined magnesite is used as a lining for the converters in the basic process for steel, and for other purposes where a very refractory material is desired. Magnesite is the favorite source of carbon dioxide in seltzer and soda water manufacture, as the treatment with sulphuric acid leaves a residue of crude epsom salts which can be recovered. It is also used in the manufacture of certain kinds of wood-pulp paper and as a covering for steam pipes.

The metal magnesium, prepared by the electrolysis of the double chloride of potassium and magnesium, and purified by distillation out of contact with air, is now made in quantity in the shape of ribbon and as coarse grains. It is used in flash lights to produce a vivid light for photographing in absence of sunlight, as a reducing agent in the preparation of some of the rarer elements, as a purifying agent to remove the last traces of oxygen from copper, nickel and steel and as a dehydrating agent for certain oils and for alcohol. The metal is steadily increasing in commercial importance.

BRUCITE.

COMPOSITION.—$Mg(OH)_2$, (MgO 69.0, H_2O 31.0 per cent.).

GENERAL DESCRIPTION.—White or gray translucent foliated masses with pearly or wax-like lustre. Also fibrous and in tabular hexagonal crystals.

Physical Characters. H., 2.5.	Sp. gr., 2.38 to 2.4.
LUSTRE, pearly or wax-like.	TRANSLUCENT.
STREAK, white.	TENACITY, sectile and flexible.
COLOR, white, bluish, greenish.	CLEAVAGE, basal.

BEFORE BLOWPIPE, ETC.—Infusible, becomes alkaline, and with cobalt solution becomes pink. Yields water in closed tube. Soluble in hydrochloric acid.

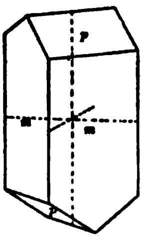
SIMILAR SPECIES.—Harder and more soluble than foliated talc or gypsum, and quite infusible.

REMARKS.—Brucite is usually found in serpentine or limestone with magnesite or hydromagnesite. On exposure it becomes coated with a white powder, and is sometimes changed to serpentine or hydromagnesite. Its most prominent American locality is at Texas, Pa., also at Fritz Island in the same State; at Brewsters, N. Y., and Hoboken, N. J.

EPSOMITE. — Epsom Salt.

COMPOSITION. — $MgSO + 7H_2O$, (MgO 16.3, SO_3 32.5, H_2O 51.2 per cent.).

FIG. 469.



GENERAL DESCRIPTION. — A delicate white fibrous efflorescence or earthy white crust with a characteristic bitter taste. Also common in solution in mineral water. Occasionally in crystals, Fig. 469, which are noticeable as representing class of the sphenoid in the orthorhombic system, p. 35. Optically —.

PHYSICAL CHARACTERS. — Transparent or translucent. Lustre, vitreous or dull. Color and streak, white. H., 2 to 2.5. Sp. gr., 1.75. Taste, bitter and salt.

BEFORE BLOWPIPE, ETC. — Fuses at first, but becomes infusible after the water of crystallization has been driven off. With cobalt solution becomes pink. In closed tube yields acid water. Easily soluble in water.

REMARKS. — Epsomite is formed by action of the sulphuric acid of decomposing sulphides, upon such magnesian minerals as serpentine and magnesite.

MAGNESITE.

COMPOSITION.—$MgCO_3$, (MgO 47.6, CO_2 52.4 per cent.), with sometimes iron or manganese replacing part of the magnesium.

GENERAL DESCRIPTION.—White chalk-like lumps and veins in serpentine. Rarely fibrous or in rhombohedral crystals closely agreeing with dolomite in form and angle.

Physical Characters. H., 3.5 to 4.5. Sp. gr., 3 to 3.12.

LUSTRE, dull, vitreous or silky, OPAQUE to translucent.
STREAK, white. TENACITY, brittle.
COLOR, white, yellow, brown. FRACTURE, conchoidal.

BEFORE BLOWPIPE, ETC.—Infusible, becomes alkaline. With cobalt solution becomes pink. Soluble with effervescence in warm hydrochloric acid, but does not effervesce in cold dilute acid. No decided precipitate is produced by addition of sulphuric acid, whereas heavy precipitates form with solutions of calcite and dolomite.

SIMILAR SPECIES.—Differs from dolomite and calcite in not yielding the calcium flame.

REMARKS.—Usually formed with serpentine by action of carbonated waters on eruptive magnesian rocks, such as olivine (chrysolite), or when the decomposition is carried further the results are magnesite and quartz. As the former is the more common decomposition, magnesite usually occurs with serpentine and also with other magnesian minerals, such as talc, brucite, dolomite, etc.

Found at Bolton and Sutton, Province of Quebec, at Texas, Pa., Barehill, Md., and at several localities in California and Massachusetts.

USES.—It is used in the lining of converters in the basic process for steel, and for lining kilns in the manufacture of sulphuric acid and for other purposes where a non-conducting and refractory material is required, especially as a covering for steam and water pipes. It is also used in obtaining carbon dioxide for soda water, the residue being converted into epsom salts. Magnesia and magnesia alba are also made from magnesite.

SPINEL. — Balas Ruby.

COMPOSITION. — $Mg(AlO_2)_2$, (MgO 28.2, Al_2O_3 71.8 per cent.). Iron, manganese and chromium are sometimes present.

FIG. 470.

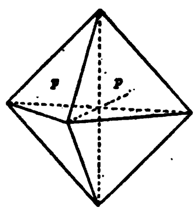


FIG. 471.

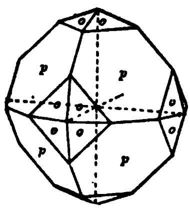
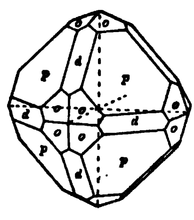


FIG. 472.



GENERAL DESCRIPTION.—Usually in octahedral, simple or twinned crystals, which cannot be scratched by steel or quartz and vary in color according to composition. Also in rolled pebbles and loose crystals.

CRYSTALLIZATION. — Isometric, the octahedron p or this modified by the dodecahedron d or the trisoctahedron $o = (a : 3a : 3a)$; $\{311\}$. Index of refraction with yellow light 1.7155.

Physical Characters. H., 8. Sp. gr., 3.5 to 4.5.

LUSTRE, vitreous. TRANSPARENT to opaque.

STREAK, white. TENACITY, brittle.

COLOR, red, green, blue, black, brown, yellow.

CLEAVAGE, octahedral.

BEFORE BLOWPIPE, ETC.—Infusible, often changing color, the red variety becomes green, then nearly colorless, finally red. In powder is turned blue by cobalt solution. Insoluble in hydrochloric or nitric acid, but somewhat soluble in sulphuric acid.

VARIETIES.—

Balas Ruby or Ruby Spinel (Magnesia Spinel).—Clear red or reddish, often transparent. Sp. gr., 3.5 to 3.6.

Ceylonite (Iron Magnesia Spinel).—Dark-green, brown, black, usually opaque.

Picotite (Chrome Spinel).—Yellowish to greenish-brown, translucent.

SIMILAR SPECIES.—Characterized by octahedral crystals and by hardness.

REMARKS.—Occurs in limestone, serpentine, gneiss, etc., associated with corundum, chondrodite, brucite, etc , and sometimes changed to talc, muscovite or serpentine. Gem specimens have been obtained at Hamburg, N. J.; San Luis Obispo, Cal., and Orange County, N. Y. The crystals also occur in many localities in North Carolina, Massachusetts and near the New York and New Jersey line. Especially abundant in Ceylon and Burmah.

USES. — Transparent varieties are used as gems.

CHAPTER XXXIV.

ALUMINUM MINERALS.

THE minerals described are:

Fluoride	**Cryolite**	$AlNa_3F_6$	Triclinic
Oxide	**Corundum**	Al_2O_3	Hexagonal
Hydroxides	**Bauxite**	$Al_2O(OH)_4$	
	Diaspore	$AlO(OH)$	Orthorhombic
	Gibbsite	$Al(OH)_3$	Monoclinic
Sulphates	*Alunogen*	$Al_2(SO_4)_3.18H_2O$	Monoclinic
	Aluminite	$(AlO\ _2SO_4.9H_2O$	Monoclinic
	Alunite	$K(AlOH)_3(SO_4)_2 + 3H_2O$	Rhombohedral
Phosphates	**Turquois**	$Al_2(OH)_3PO_4.H_2O$	
	Wavellite	$Al_6(OH)_6(PO_4)_4 + 9\,H_2O$	Orthorhombic
Beryllium-Aluminate	**Chrysoberyl**	$BeAl_2O_4$	Orthorhombic

Aluminum is also present in many silicates, and is an essential constituent of all clays.

The minerals of aluminum, aside from the clays, have important commercial applications, which may be roughly classified as: I. Ores of aluminum. II. Abrasive materials. III. Gems.

Ores of Aluminum.

BAUXITE to the amount of 40,700 long tons was mined in Georgia and Alabama in 1903,* these two states having the only known American deposits of importance. This ore is the source of most of the aluminum of commerce and is also used in the production of alum and other compounds of aluminum used extensively in dyeing and calico printing. The output of the mineral is steadily increasing.

GIBBSITE, when found with bauxite, is also used as an ore but is not found in quantity. Corundum is too difficult to obtain and has too high a value as abrasive material, and the abundant clays and silicates contain a much smaller percentage of aluminum, and before using, need to be decomposed and freed from silica.

Metallic aluminum, formerly prepared only by reduction of the chloride by the metal sodium, is now made in large quantities

* *Engineering and Mining Journal*, 1904, p. 4.

by electrolysis. In 1903 there were produced in this country 3,750* tons of the metal, which averaged about 32 cents per pound.

The ore is heated with sodium carbonate to low redness, in order to produce sodium aluminate without rendering the silica or iron soluble. On dissolving out the sodium aluminate with water and passing carbon dioxide through the solution, aluminum hydroxide is formed, which yields the oxide when heated. By this mode of procedure most of the iron and silicon are separated, which would otherwise be reduced by the current and alloyed with the aluminum. In a more recent process the impurities in the bauxite are removed by fusing the ore with carbon in an electric furnace whereby iron, silicon and titanium are reduced or converted into carbides and separate on top of the aluminum oxide formed.

For the production of the pure metal the oxide is decomposed by electrolysis in a fused solvent which protects the metal from contact with oxygen. The Hall and Heroult processes consist in the electrolysis of the oxide in a fused bath of cryolite or the mixed fluorides of sodium and aluminum. The Hall process is carried on in iron tanks, the bottom and sides of which are thickly lined with carbon. The tanks serve as the negative electrodes and are filled with the cryolite flux, to which a little fluorite is added. The positive electrodes are carbon cylinders, which dip into the electrolyte.

The cylinders are first lowered until they touch the bottom of the tank, and the ground cryolite is melted as a result of the poor contact. The cylinders are then raised, and the current thenceforth passes through the melted liquid. The alumina is now added, and is immediately dissolved by the flux and decomposed by the current. The metal settles at the bottom of the bath, while the oxygen combines with the carbon of the anode and escapes as carbon dioxide. The metal is removed from time to time, alumina is again added and thus the operation is continuous.

Aluminum is used where lightness, strength and non-corrosiveness are desirable, *e. g.*, in some scientific apparatus, in fancy articles, to a limited extent in cooking utensils. It is replacing sheet copper and zinc, and is used as bronze powder and aluminum leaf for silvering letters and signs. It is of growing importance as a sub-

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* *Engineering and Mining Journal*, 1904, p. 3.

stitute for stone and zinc in lithographing and is used in large quantities for electrical conductors.* Aluminum is especially sonorous and is now used in the Austrian army for drums, and the substitution of aluminum for brass in the other band instruments is being tried.

Two interesting uses of aluminum in metallurgy are: The welding of wrought iron pipes, rails and steel castings, in place, by the heat developed by oxidation of powdered aluminum mixed with oxide of iron (Thermite); the prevention of blow-holes in castings of steel, copper or zinc by the addition of less than one per cent. of aluminum to the melted metal.

The alloys of aluminum are extensively used, especially the alloy with copper, known as aluminum bronze, which contains usually as much as ten per cent. of aluminum. It is extremely tough and is extensively applied in machinery, especially mine machinery, engine castings, etc. The alloys with zinc, nickel and tin are also of importance and to some extent are replacing brass. The alloys with zinc are malleable and ductile and when chilled possess a high tensile strength. Alloys with tungsten are also growing in importance.

CRYOLITE to the amount of about 10,000 tons per year is imported into the United States from Greenland, its only important locality, and is used in making sodium carbonate, alum and calcium fluoride. A small amount of cryolite is used as a flux in the manufacture of aluminum as above described.

Abrasive Materials.

CORUNDUM and emery were produced in the United States in 1901 to the amount of 4,257 † tons. About 8,000 tons of corundum and emery were imported. The artificial production in quantity of an extremely hard carbide of silicon, known as carborundum, is supplanting these natural abrasives to the extent of about 2,000 tons per year.

Gems.

CORUNDUM (the varieties ruby and sapphire), TURQUOIS and CHRYSOBERYL are all found of sufficient beauty to be classed as gems or precious stones. In this country sapphires have been

* *Engineering and Mining Journal*, 1899, p. 8.

† *Mineral Resources*, 1902, p. 886.

found in Montana, but their status in the gem market is not yet very well defined. A considerable amount of turquois of a marketable grade has been mined in New Mexico and new deposits are reported in Nevada.

CRYOLITE.—Eisstein.

COMPOSITION.—$AlNa_3F_6$. (Al 12.8, Na 32.8, F 54.4 per cent.).

GENERAL DESCRIPTION —Soft, translucent, snow-white to colorless masses, resembling spermaceti or white wax in appearance. Occasionally with groups of triclinic crystals so slightly inclined as to closely approach cubes and cubic octahedrons in angle and form.

Physical Characters. H., 2.5. Sp. gr., 2.95 to 3.

LUSTRE, vitreous or wax-like. TRANSLUCENT or transparent.

STREAK, white. TENACITY, brittle.

COLOR.—Colorless, white, brown.

CLEAVAGE.—Basal and prismatic, angles near 90°.

BEFORE BLOWPIPE, ETC.—Fuses very easily, with strong yellow coloration of the flame, to a clear globule, opaque when cold. With cobalt solution, becomes deep blue. In closed tube, yields acrid fumes, which attack and etch the glass. Soluble in acid without effervescence.

SIMILAR SPECIES.—Characterized by its easy fusibility, and fumes which attack glass.

REMARKS.—Found at Ivigtut, Greenland, as a large bed in a granite vein, and contains, scattered through it, crystals of siderite, quartz, chalcopyrite and galenite. This is the only locality where cryolite is produced in commercial quantities, but here the supply seems inexhaustible. Small amounts have been found at Miask, Urals, and in the United States at Pike's Peak, Colorado.

USES.—It is used in the manufacture of sodium carbonate, and aluminum hydroxide, and is made into alum. The by-product, calcium fluoride, is sold to smelters and glass manufacturers. Cryolite is also used as a flux or bath in the manufacture of aluminum.

CORUNDUM.—Sapphire, Ruby, Emery.

COMPOSITION.—Al_2O_3, (Al 52.9, O 47.1 per cent.).

GENERAL DESCRIPTION.—With the exception of the diamond, the hardest of all minerals. Occurs in three great varieties, which are most conveniently described separately.

Sapphire or Ruby.—Transparent to translucent, sometimes in crystals and of fine colors—blues, reds, greens, yellows, etc.

Adamantine Spar or Corundum.—Coarse crystals or masses, with nearly rectangular cleavage, or granular, slightly translucent, and usually in some blue, gray, brown or black color.

Emery.—Opaque, granular corundum, intimately mixed with hematite or magnetite, usually dark-gray or black in color.

FIG. 473.

Corundum Crystals, Ceylon. U. S. National Museum.

CRYSTALLIZATION.—Hexagonal. Scalenohedral class, p. 42. Axis $\dot{c} = 1.363$. Crystals often rough and rounded. Second order pyramids predominate as *n*, *o*, and *w* intersecting the vertical

FIG. 474.

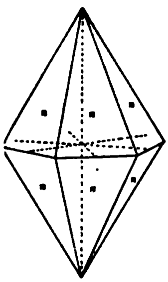


FIG. 475.

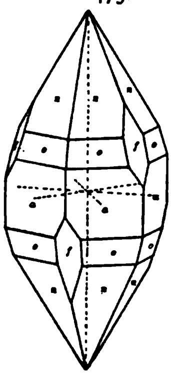
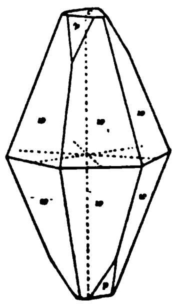


FIG. 476.



axis at respectively $\frac{1}{3}c$, $\frac{4}{3}c$ and $2c$. Unit rhombohedron p and the more acute form f ($2c$) also occur. Supplement angles $nn = 51°\ 58'$; $oo = 57°\ 38'$; $ww = 56°$.

Optically —, with rather strong refraction but weak double refraction ($\alpha = 1.759$; $\gamma = 1.767$).

Physical Characters. H., 9. Sp. gr., 3.95 to 4.11.

LUSTRE, vitreous or adamantine. TRANSPARENT to opaque.
STREAK, white. TENACITY, brittle to tough.
COLOR, blue, red, green, yellow, black, brown or white.
CLEAVAGE, rhombohedral, angle of 86° 4'.

BEFORE BLOWPIPE, ETC.—Infusible and unaltered, alone or with soda, or sometimes improved in color. Becomes blue with cobalt solution at high heat. Insoluble in acids and only slowly soluble in borax or salt of phosphorus.

REMARKS.—Occurs in granular limestone, granite, gneiss and other crystalline rocks and in the gravel of river-beds. It is usually associated with chloritic minerals, rarely with quartz, and is frequently found altered, and many alteration products occur, as spinel, feldspar, mica, tourmaline, cyanite, fibrolite, etc. The American localities producing corundum or emery are: Raburn County, Ga.; Macon, Clay and Jackson Counties, N. C.; Westchester County, N. Y.; Chester County, Pa., and Chester, Mass. Fair-sized rubies and sapphires have been obtained near Helena, Montana, and at several localities in North Carolina. The finest rubies are obtained from Upper Burmah and Ceylon.

USES.—Sapphire and ruby, when clear and transparent, are valuable gems, the ruby sometimes being more highly valued than the same weight of diamond. The various colors have different names; Blue, *sapphire;* red, *ruby;* yellow, *oriental topaz;* green, *oriental emerald;* purple, *oriental amethyst.* Adamantine spar and emery are the most important abrasive materials, and thousands of tons are used in grinding and polishing glass, gems and metals. Corundum can be used in the electric smelting processes for aluminum, but its price makes this unprofitable.

BAUXITE.

COMPOSITION.—$Al_2O(OH)_4$, with usually part of the Al replaced by Fe.

GENERAL DESCRIPTION.—Disseminated, rounded grains, oolitic and sponge-like to clay-like masses. Also fine-grained, compact. Usually white, or, if ferruginous, will be yellow, brown or red.

FIG. 477.

Bauxite, Bartow County, Ga. U. S. National Museum.

Physical Characters. H., 1 to 3. Sp. gr., 2.4 to 2.5.

LUSTRE, dull or earthy. OPAQUE.

STREAK, like color. TENACITY, brittle.

COLOR, white, red, yellow, brown or black.

BEFORE BLOWPIPE, ETC.—Infusible. Becomes deep blue with cobalt solution, and may become magnetic in reducing flame. In closed tube yields water at high heat. Soluble with difficulty in hydrochloric acid.

REMARKS.—Bauxite may have been deposited from solution in hot alkaline waters or may have resulted from alteration of corundum. It is usually found with clay or kaolin associated with other aluminum minerals. Large deposits exists at Beaux, France, Lake Wochein, Carniola, and in Antrim, Ireland. In the United States it is mined at Floyd county, Ga., and Bauxite, Ark. The production at these two places is extensive.

USES.—Is the chief source of aluminum, and is also used in the linings of basic converters, Siemens-Martin furnaces, etc., and in the manufacture of alum.

DIASPORE.

COMPOSITION.—AlO(OH), (Al_2O_3 85.1, H_2O 14.9 per cent.).

GENERAL DESCRIPTION.—Thin, flat, orthorhombic prisms, foliated masses and thin scales. When pure, it is transparent and white or pinkish in color. When impure, it is often brown

PHYSICAL CHARACTERS.—Transparent to nearly opaque. Lustre, pearly and vitreous. Color, gray, white, pink, yellow, brown. Streak, white. H., 6.5 to 7. Sp. gr., 3.3 to 3.5. Very brittle. Cleaves into plates.

BEFORE BLOWPIPE, ETC.—Infusible. Usually decrepitates. With cobalt solution, becomes deep blue. In closed tube, yields water at high heat. Insoluble in acids.

SIMILAR SPECIES.—Distinguished by its hardness, cleavage and decrepitation.

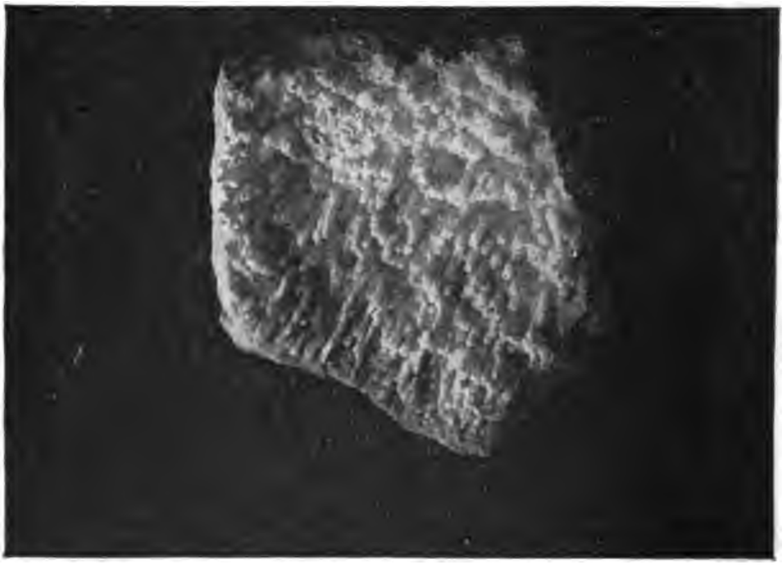
REMARKS.—Occurs with corundum and its associates.

GIBBSITE.

COMPOSITION.—$Al(OH)_3$, (Al_2O_3 65.4, H_2O 34.6 per cent.).

GENERAL DESCRIPTION.—A white or nearly white mineral, usually occurring in small stalactites or thin mamillary crusts, with smooth surface and sometimes fibrous internal structure. Rarely in small six-sided monoclinic crystals. When breathed upon, it has a strong clay-like odor.

FIG. 478.



Gibbsite, Richmond, Mass. N. Y. State Museum.

Physical Characters. H., 2.5 to 3.5. Sp. Gr., 2.38.

LUSTRE, faint vitreous. TRANSLUCENT.
STREAK, white. TENACITY, brittle to tough.
COLOR, white, greenish, reddish, yellow. CLEAVAGE, basal.

Before Blowpipe, Etc.—Infusible, exfoliates, glows and becomes white. With cobalt solution becomes deep blue. In closed tube yields water. Soluble in hydrochloric or sulphuric acid.

Remarks.—If gibbsite could only be found in quantity it would be even more valuable than bauxite for the manufacture of aluminum. No large deposits, however. are known, and the mineral is not mined except when it occurs in comparatively small quantity with the bauxite of Georgia and Arkansas. The mineral is found in even smaller quantity at Richmond and Lenox, Mass., and in Dutchess and Orange counties, N. Y.

ALUNOGEN.

Composition.—$Al_2(SO_4)_3 + 18\ H_2O$, (Al_2O_3 15.3, SO_3 36.0, H_2O 48.7 per cent.).

General Description.—A delicate fibrous crust of white or yellow color. Sometimes massive. Tastes like alum.

Physical Characters.—Translucent. Lustre, vitreous or silky. Color, white yellowish or reddish. Streak, white. H., 1.5 to 2. Sp. gr., 1.6 to 1.8. Taste, like alum.

Before Blowpipe, Etc.—Melts in its own water of crystallization, but becomes infusible. It is colored deep blue by cobalt solution. In closed tube yields much acid water. Easily soluble in water.

Remarks.—Formed by action of sulphuric acid of decomposing sulphides upon aluminous shales. Also formed during volcanic action.

ALUMINITE.

Composition. — $(AlO)_2SO_4.9H_2O$, (Al_2O_3 29.6, SO_3 23.3, H_2O 47.1 per cent.).

General Description.—Usually found in white rounded or irregular masses of chalk-like texture and peculiar harsh feeling.

Physical Characters.—Opaque. Lustre, dull or earthy. Color and streak, white. H., 1 to 2. Sp. gr., 1.66. Meagre to the touch and adheres to the tongue.

Before Blowpipe, Etc.—Infusible. In closed tube yields much acid water. With cobalt solution becomes deep blue. Easily soluble in acid.

Remarks.—Found in clay beds. Expense of transportation alone keeps aluminite from the list of aluminium ores. Quite extensive deposits occur near Silver City, New Mexico, also near Trinidad, Colo , and in others of the Western States.

ALUNITE. — Alum Stone.

Composition. — $K(AlOH)_3(SO_4)_2 + 3\ H_2O$, ($Al_2O_3$ 37.0, K_2O 11.4, SO_3 38.6, H_2O 13 per cent.).

General Description.—Occurs fibrous and in tabular to nearly cubic rhombohedral crystals, or so intermixed with a siliceous material as to form a hard granular and nearly white rock.

Physical Characters. H., 3.5 to 4. Sp. gr., 2.58 to 2.75.

Lustre, vitreous. Transparent to nearly opaque.

Streak, white. Tenacity, brittle.

Color, white, grayish or reddish.

BEFORE BLOWPIPE, ETC.—Infusible and decrepitates. With cobalt solution becomes deep blue. With soda infusible, but the mass will stain silver. In closed tube yields water at a red heat. Imperfectly soluble in hydrochloric or sulphuric acid.

REMARKS.—Formed by action of sulphur dioxide and steam upon trachyte or allied rocks. Occurs at Tolfa, Italy, in Hungary and in Rosita Hills, Colorado.

USES.—By roasting and lixivation with water, alum is obtained, and the Tolfa rock is so treated for manufacture of Roman alum. The rock is also used for millstones.

TURQUOIS.

COMPOSITION.—$Al_2(OH)_3PO_4 \cdot H_2O$ and always contains some copper which gives it color.

GENERAL DESCRIPTION.—Sky blue to green opaque nodules or veins, also in rolled masses.

Physical Characters. H., 6. Sp. gr., 2.6 to 2.83.

LUSTRE, dull or wax-like. OPAQUE or slightly translucent.
STREAK, white or pale green. TENACITY, rather brittle.
COLOR, sky-blue to apple-green.

BEFORE BLOWPIPE, ETC.—Infusible, becomes brown and colors the flame green. In salt of phosphorus yields bead greenish-blue when cold, which on charcoal in the reducing flame becomes opaque red. Soluble in hydrochloric acid, the solution becoming fine blue with ammonia. In a nitric acid solution of ammonium molybdate produces a yellow precipitate on boiling.

SIMILAR SPECIES.—It is harder than chrysocolla.

REMARKS.—Turquois is mined in the United States at Los Cerrillos in New Mexico, and fine material is obtained. Also in Grant county, New Mexico. Previous to the opening of these mines turquois had been obtained almost altogether from the famous Persian locality and from Arabia. The mineral is also known to occur in Arizona, California, Colorado and Nevada.

USES.—As a gem.

WAVELLITE.

COMPOSITION.—$Al_6(OH)_6(PO_4)_4 + 9H_2O$, ($Al_2O_3$ 38.0, P_2O_5 35.2, H_2O 26.8 per cent.). F is sometimes present.

GENERAL DESCRIPTION.—Hemispherical masses which, when broken yield complete or partial circles with radiating crystals.

rarely large enough to be measured. Occasionally stalactitic. Color most frequently white, green or yellow.

FIG. 479.

Physical Characters. H., 3.5 to 4. Sp. gr., 2.31 to 2.34.

LUSTRE, vitreous. TRANSLUCENT.

STREAK, white. TENACITY, brittle.

COLOR, colorless, white, yellow, green, brown, blue, black.

BEFORE BLOWPIPE, ETC.—Whitens, swells, and splits, but does not fuse. With cobalt solution becomes deep blue. In closed tube yields acid water. Soluble in hydrochloric acid. Ammonium molybdate produces a yellow precipitate from nitric acid solutions.

REMARKS.—In the United States is most abundant at Magnet Cove, Ark., West Whiteland, Pa., and Silver Hill, N. C. It is without industrial use.

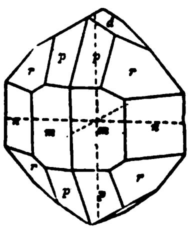
Lazulite. — $(Mg.Fe.Ca)Al_2(OH)_2(PO_4)_2$, is found in clay, slate, and quartzite as azure-blue, acute, monoclinic pyramids and masses. Usually opaque.

CHRYSOBERYL.

COMPOSITION. — $BeAl_2O_4$, (BeO 19.8, Al_2O_3 80.2 per cent.).

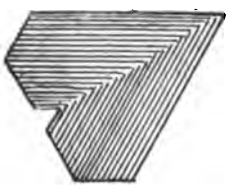
GENERAL DESCRIPTION. — Pale green or yellowish tabular crys-

FIG. 480.



Urals.

FIG. 481.



Haddam, Conn.

tals; thicker deep emerald-green crystals, which by transmitted light are a purplish red; and rolled pebbles like green bottle glass, often with an internal opalescence. Very hard.

CRYSTALLIZATION. — Orthorhombic $\breve{a} : \bar{b} : \dot{c} = 0.470 : 1 : 0.580$. Often flat contact twins with feather-like striations, Fig. 481. Alexandrite occurs in simple, Fig. 480, or twinned crystals showing unit pyramid p and prism m with brachy-pyramid $r = (2\breve{a} : \bar{b} : 2c)$, $\{121\}$; and prism $n = (2\breve{a} : \bar{b} : \infty c)$, $\{120\}$. Supplement angles are $mm = 50° \ 21'$; $nn = 86° \ 28'$; $pp = 40° \ 7'$; $rr = 72° \ 17'$.

Optically +. Axial plane the brachy-pinacoid. Acute bisectrix vertical. Pleochroic.

Physical Characters. H., 8.5. Sp. gr., 3.5 to 3.84.

LUSTRE, vitreous to greasy. TRANSLUCENT to transparent.

STREAK, white. TENACITY, brittle.

COLOR, pale yellowish green to emerald green.

BEFORE BLOWPIPE, ETC.—Infusible. In powder, is turned blue by cobalt solution. Insoluble in acids.

VARIETIES.—*Alexandrite*, the deep emerald-green variety, which is columbine red by transmitted light.

Cymophane or Cats Eye.—Yellowish-green and opalescent.

REMARKS. — No fine gems have been found in the United States, although the mineral occurs sparingly in Stowe, Peru and Canton, Me., New York City, see Fig. 189, and Greenfield, N. Y., Haddam, Conn. The best gems are obtained from Ceylon, the Ural Mountains and Brazil.

USES. — As a gem, especially the alexandrite and cat's eye.

CHAPTER XXXV.

BORON, SULPHUR, TELLURIUM, HYDROGEN AND CARBON MINERALS.

THE BORON MINERALS.

THE minerals described are:

Acid	**Sassolite**	H_3BO_3	Monoclinic
Borates	**Borax**	$Na_2B_4O_7, 10H_2O$	Monoclinic
	Ulexite	$CaNaB_5O_9.8H_2O$	
	Colemanite	$Ca_2B_6O_{11}.5H_2O$	Monoclinic
	Boracite	$Mg_7Cl_2B_{16}O_{30}$	Isometric

Boron is also a constituent of the common silicates tourmaline and datolite.

Commercial borax is manufactured from all the minerals mentioned, and has important uses, based either on its power to unite with almost any oxide to form a fusible compound, or upon its antiseptic or detergent properties. It is used in welding, as basis of enamels on metal or porcelain, as a flux, as an antiseptic in packing meat, in antiseptic powders and soaps, and in washing, dyeing, and tanning.

Sassolite, to the extent of about 2500 tons yearly, is obtained by condensing and evaporating the steam issuing from fumaroles in the mountains of Tuscany. About 8000 tons of pandermite (colemanite) are annually obtained in Asia Minor. Boracite is from the mines at Stassfurt, Germany. Large deposits of calcium borate occur in Chili, Argentina and Bolivia and are mined to the extent of some 17,000 tons annually. In this country the main output is from the colemanite deposits near Daggett, California, although a small output is still maintained from the "marsh" deposits of borax in Nevada. In 1902 borax and boric acid were extracted to the extent of 20,004 tons in California.

When the crude material is borax with other sodium and calcium salts, the borax is extracted by boiling in hot water, cooling and crystallizing. The calcium borates are decomposed by sodium

* *Mineral Resources*, 1902, p. 892.

carbonate or sulphate to form borax, or by sulphuric or hydrochloric acid if boric acid is first to be produced.

SASSOLITE. — Natural Boracic Acid.

COMPOSITION. — H_3BO_3, (B_2O_3 56.4, H_2O 43.6 per cent.).

GENERAL DESCRIPTION. — Small white or yellowish scales, of pearly lustre, acid taste, and somewhat unctuous feel. Rarely stalactitic or in minute monoclinic crystals. Occurs chiefly in solution or vapor in volcanic regions.

Physical Characters. H., 1. Sp. gr., 1.43.

LUSTRE, pearly.	TRANSLUCENT.
STREAK, white.	TENACITY, brittle.
COLOR, white or yellowish.	TASTE, sour or acid.

BEFORE BLOWPIPE, ETC.—Fuses easily with intumescence to a clear glass without color, but colors the flame yellowish-green. In closed tube, yields water. Soluble in water.

REMARKS.—In the region of volcanoes sassolite is brought to the surface in the jets of steam, collects in the water from these jets, and, to some extent, forms also a crust more or less solid. The only productive locality is in Tuscany. It also forms a small proportion of the boron compounds at the California borax localities.

USES.—It is an important source of borax.

BORAX.—Tinkal.

COMPOSITION.—$Na_2B_4O_7.10H_2O$, (B_2O_3 36.6, Na_2O 16.2, H_2O 47.2 per cent.).

GENERAL DESCRIPTION.—A glistening, white or nearly white efflorescence or constituent of certain soils, but more frequently in solution in lakes, or as well-formed monoclinic crystals in the mud of these lakes. The crystals closely resemble those of pyroxene in form and angle.

Physical Characters. H., 2 to 2.5. Sp. gr., 1.69 to 1.72.

LUSTRE, vitreous to dull.	TRANSLUCENT to opaque.
STREAK, white.	TENACITY, brittle.
COLOR, white, gray, bluish, greenish.	TASTE, alkaline.

BEFORE BLOWPIPE, ETC.—Swells greatly and fuses to a clear glass. Colors flame yellow, and if mixed to a paste with a flux of acid potassium sulphate and powdered fluorite, and fused, it will

color the flame bright green. In closed tube, swells, blackens, yields much water and a burnt odor. Soluble in water. If treated with a few drops of sulphuric acid, covered with alcohol, and the alcohol set on fire, a green flame is obtained.

REMARKS.—Borax in the United States is produced from the deposits existing in both Nevada and California. The Nevada localities are mainly in Esmeralda County; while those of California are in Lake, Bernardino and Inyo Counties.

USES. In welding, soldering, soap-making, glass-making, glazing, as a flux in assaying, refining and testing metals, as a preservative, in medicine, and as chief ingredient of many washing powders and antiseptic preparations.

ULEXITE.—Boronatrocalcite.

COMPOSITION.—$CaNaB_5O_9.8H_2O$, (B_2O_3 43.0, CaO 13.8, Na_2O 7.7, H_2O 35.5 per cent.).

GENERAL DESCRIPTION.—White, rounded masses (cotton-balls) of loosely-compacted, intertwined, silky fibres, which are easily pulverized between the fingers.

Physical Characters. H., 1. Sp. gr., 1.65.

LUSTRE, silky.	TRANSLUCENT.
COLOR and STREAK, white.	TENACITY, brittle.

BEFORE BLOWPIPE, ETC.—Fuses very easily, with intumescence to a clear glass. Colors flame intense yellow, and will yield green flame, as with borax. In closed tube yields water. Soluble in acids.

REMARKS.—Occurs in dry lakes or on the banks surrounding partially dried lakes, with halite, gypsum, glauberite, borax, etc. Is probably formed by the action of soluble calcium salts on boracic acid and borax in solution in the same waters. It is abundant in Esmeralda County, Nevada, and is also found in several of the California borax localities and in the gypsum beds of Nova Scotia. Large deposits also occur in the dry plains at the north of Chili.

USES.—It is a source of part of the borax of commerce.

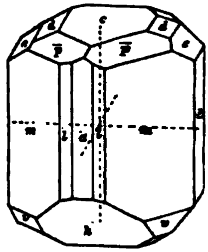
COLEMANITE.—Priceite, Pandermite.

COMPOSITION.—$Ca_2B_6O_{11} + 5H_2O$, (B_2O_3 50.9, CaO 27.2, H_2O 21.9 per cent.).

GENERAL DESCRIPTION.—Occurs in groups of colorless trans-

parent crystals resembling those of datolite but usually larger, and in simpler wedge-shaped forms. Also found in compact white masses like porcelain and in loosely aggregated chalk-like masses.

FIG. 482.



CRYSTALLIZATION. — Monoclinic. Axes $\grave{a} : \bar{b} : \acute{c} = 0.775 : 1 : 0.541$; $\beta = 69° 51'$. Common faces are: $l = (2a : b : \infty c)$, $\{120\}$; $v = (a : b : 2c)$, $\{221\}$; $e = (\infty a : b : 2c)$, $\{021\}$; $h = (a : \infty b : 2c)$, $\{201\}$. Usually short prismatic and highly modified. Supplement angles, $mm = 72° 4'$; $mc = 73° 49'$; $ac = 69° 51'$.

Physical Characters. H., 4 to 4.5. Sp. gr., 2.26 to 2.48.

LUSTRE, vitreous to dull.	TRANSPARENT to opaque.
STREAK, white.	TENACITY, brittle.
COLOR, white or colorless.	CLEAVAGE, parallel clino-pinacoid.

Before Blowpipe, Etc. — Decrepitates, exfoliates and fuses imperfectly, coloring the flame green. Insoluble in water, easily soluble in hot hydrochloric acid with separation of boric acid on cooling.

VARIETIES.

Priceite. — Loosely compacted white chalky masses.

Pandermite. — Firm compact porcelain-like white masses.

REMARKS. — Priceite occurs in Curry County, Oregon, in layers between slate and steatite. Pandermite is found in a bed beneath gypsum near Panderma on the Sea of Marmora. Colemanite at Inyo and San Bernardino Counties, Cal., with celestite and quartz. Especially abundant near Daggett in the Mojave Desert.

USES. — Is an important source of borax and yields a large part of the American output.

BORACITE. — Stassfurtite.

COMPOSITION. — $Mg_7Cl_2B_{16}O_{30}$ (B_2O_3 62.57, MgO 31.28, Cl 7.93 per cent.).

GENERAL DESCRIPTION. — Snow-white, rather soft masses (stassfurtite) and small

FIG. 483.

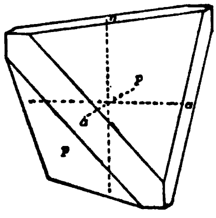
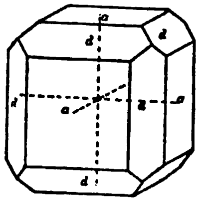


FIG. 484.



hard glassy isometric crystals of the hextetrahedral class, p. 56, usually showing the tetrahedron *p* with or without the cube *a* and dodecahedron *d*. Strongly pyroelectric.

PHYSICAL CHARACTERS. — Transparent to opaque. Lustre, vitreous. Color, white, yellowish, greenish. Streak, white. H., 7 (crystals), 4.5 (masses). Sp. gr., 2.9 to 3. Brittle.

BEFORE BLOWPIPE, ETC. — Fuses easily with intumescence, to a white glass and colors the flame yellowish green. In closed tube yields no water or but little. Soluble slowly in hydrochloric acid. Strongly heated with cobalt solution becomes violet.

REMARKS. — Occurs in deposits of halite, gypsum, anhydrite, and especially in the immense beds of potassium and magnesium salts at Stassfurt, Prussia.

THE SULPHUR AND TELLURIUM MINERALS.

The minerals described are:

Elements	**Sulphur**	S	Orthorhombic
	Tellurium	Te	*Hexagonal*

The principal sulphur minerals, however, are the sulphides and sulphates elsewhere described.

According to the estimate of J. Struthers,* the United States consumed a total of 471,647 long tons of sulphur in 1902. Of this amount 177,480 tons was in the form of brimstone, almost wholly imported from Sicily, and 294,167 tons was present in pyrite from which it was burned. About two-thirds of the pyrite was imported and mainly from the Rio Tinto mines of Spain. Sulphur is also recovered in large quantities from the former waste products of gas works, Leblanc soda factories and other chemical works. Considerable quantities are also burned off from the sulphides of zinc and copper during the recovery of the metals and in a few localities, notably in Germany, the sulphur dioxide fumes are utilized in the manufacture of sulphuric acid.

Nine-tenths of the world's supply of native sulphur is obtained from the Island of Sicily. In this country 12,054 long tons were produced in 1903.†

Sulphur is extracted from the native mineral by simple fusion and consequent separation from the gangue. The common method in use in Sicily involves the burning of part of the sulphur to melt the remainder, causing heavy loss of the element. The crude sulphur may be refined by sublimation. Pyrite is burned directly in specially constructed furnaces, the sulphur dioxide produced being used almost solely in the manufacture of sulphuric acid.

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* *Mineral Industry*, 1902, p. 579.

† *Engineering and Mining Journal*, 1904, p. 5.

TELLURIUM is included in this section on account of its close chemical relation to sulphur. It has no commercial importance, but its compounds with gold and silver are of great economic importance.

SULPHUR. — Brimstone.

COMPOSITION. — S, sometimes with traces of tellurium, selenium, or arsenic. Often mixed with clay or bitumen.

GENERAL DESCRIPTION. — Translucent or transparent, resinous, crystals of characteristic yellow color. Also in crusts, stalactites, spherical shapes, and powder. Sometimes brown or green.

FIG. 485.

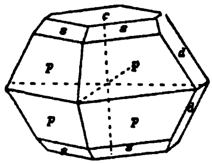
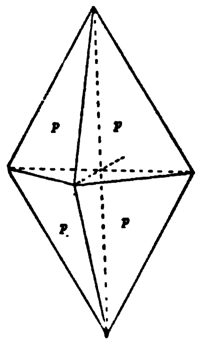


FIG. 486.



CRYSTALLIZATION.—Orthorhombic. Axes $\breve{a} : \bar{b} : c = 0.813 : 1 : 1.903$. Usually the pyramid p, sometimes modified by the base c, the pyramid $s = (\breve{a} : \bar{b} : \frac{1}{3} c)$, $\{113\}$; or the dome $d = (\infty \breve{a} : \bar{b} : c)$, $\{011\}$. Supplement angles $pp = 73° 34'$; $ss = 53° 9'$; $cd = 62° 17'$.

Optically $+$. Axial plane, the brachy-pinacoid. Acute bisectrix vertical. Axial angle with yellow light $2V = 69° 5'$.

Physical Characters. H., 1,5 to 2.5. Sp. gr., 2.05 to 2.09.

LUSTRE, resinous. TRANSPARENT to translucent.

STREAK, white or pale yellow. TENACITY, brittle.

COLOR, yellow, yellowish-orange, brown, or gray,

CLEAVAGE, parallel to base, prism and pyramid, not perfect.

BEFORE BLOWPIPE, ETC.—Melts easily, then takes fire and burns with a blue flame aud suffocating odor of sulphur dioxide. In closed tube melts and yields a fusible sublimate, brown hot, yellow cold, and if rubbed on a moistened silver coin the coin is blackened. Insoluble in acids.

REMARKS. — Formed in large deposits by the decomposition of sulphides, or of sulphates, especially gypsum, which by water and decaying organic matter are reduced to the sulphide with subsequent production of hydrogen sulphide which on decomposition forms sulphur. Sulphur is also deposited from hot springs.

The great sulphur producing region of the world is the island of Sicily. Deposits are numerous in the United States, and are worked in Calcasieu Parish, La., in Beaver County, Utah, and at Rabbit Hole Springs, Nevada. Important mines are operated in Japan. Extensive deposits are also known in California, Wyoming and Texas. Less important occurrences are numerous.

USES. — Sulphur is used in immense quantities for the manufacture of sulphuric acid, gunpowder, matches, rubber goods, bleaching, medicines, etc. Large quantities of it are recovered in various chemical and metallurgical operations as by-products.

TELLURIUM.

COMPOSITION.—Te with a little Se, S, Au, Ag, etc.

GENERAL DESCRIPTION.—A soft tin white mineral of metallic lustre occurring fine grained or in minute hexagonal prisms.

PHYSICAL CHARACTERS.—Opaque. Lustre, metallic. Color and streak, tin-white. H., 2 to 2.5. Sp. gr., 6.1 to 6.3. Rather brittle.

BEFORE BLOWPIPE, ETC.—On charcoal fuses easily, volatilizes, coloring flame green and forming a white coat, which is made rose color by transferring to porcelain and moistening with sulphuric acid. Soluble in hydrochloric acid.

THE HYDROGEN MINERALS.

HYDROGEN is a constituent of many minerals, being present in combination and as water of crystallization. It is present to a limited extent in natural gas and in volcanic gases; it escapes in combination with sulphur from many sulphur springs and, in combination with carbon, occurs as marsh gas, petroleum, ozocerite, etc. Its compound WATER is properly included as a mineral and has been of the utmost importance in mineral formation and alteration (see p. 197), and for that reason is considered here. The uses to which water is put are so numerous and well known that they scarcely need mention. In 1902 mineral waters to the extent of 64,859,451 gallons were sold in the United States.*

WATER. — Ice, Snow.

COMPOSITION.—H_2O, (H., 11.1, O., 88.9 per cent.).

GENERAL DESCRIPTION. — *Ice or snow* at or below 0° C. *Water* from 0° to 100° C. *Steam* above 100° C., or aqueous vapor at all ordinary temperatures.

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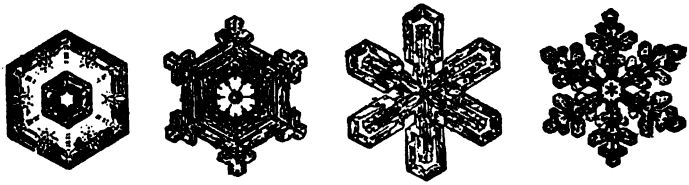
* *Mineral Resources*, 1902, p. 993.

CRYSTALLIZATION.—Hexagonal. Axis $\dot{c} = 1.403$ approximately. As snow, the crystals are principally compound star-like forms branching at 60° and of great diversity. Simple crystals are sometimes found as hail. Optically +.

FIG. 487. FIG. 488. FIG. 489. FIG. 490.



Magnified Snow Crystals.

Physical Characters. H. (ice), 1.5. Sp. gr. (ice), 0.91.

LUSTRE, vitreous. TRANSPARENT.

STREAK, colorless. TENACITY, brittle.

COLOR, white or colorless, pale blue in thick layers.

Tasteless if pure.

BEFORE BLOWPIPE, ETC.—Melts at 0° C. Under pressure of 760 mm. boils at 100° C. and is converted into steam.

REMARKS.—Rarely pure, usually containing air, carbon dioxide, some of the salts of calcium, magnesium, sodium, potassium, etc., and even traces of the metals. When pure it is tasteless and a universal solvent.

THE CARBON MINERALS.

The definite minerals described are:

Elements	**Diamond**	C	Isometric
	Graphite	C	Hexagonal

In addition to these there are a large number of gaseous, liquid and solid carbon compounds, of economic importance which are on the border line of mineralogy, occurring naturally but being generally without definite composition or crystalline form. Among these the most important are:

NATURAL GAS, PETROLEUM, ASPHALTS AND BITUMENS, FOSSIL RESINS, MINERAL WAXES, COAL.

Carbon also exists in all organic matter, in all carbonates; in the carbon dioxide of the air; and in natural gas.

DIAMONDS have been found in this country, but practically, the production for the world is from the South African mines, with a

limited amount from New South Wales and from Brazil. Nearly two and one-half million carats were mined in Kimberley, South Africa, in 1902.* Extensive new deposits have been discovered recently near Pretoria.

GRAPHITE is mined in New York, Pennsylvania, and Rhode Island, and to a limited extent in a few other states. In 1903 the output of crystalline graphite in the mines of this country was 2088 tons.† Amorphous graphite to the extent of 4739 tons was also produced.‡ The total product of the world is over 50,000 tons annually, obtained mainly from Ceylon and Austria. The uses of graphite are numerous, the best known being pencils, crucibles, stove polish, lubricants, paints for iron, foundry facings, powder glazing, electrotyping, etc.

NATURAL GAS.

Natural gas issues from the earth in many localities but mainly through borings or wells driven to control its outflow. It consists essentially of the gas methane, more commonly known as marsh gas, which ordinarily is produced when organic matter decomposes under water or out of contact with air. It also contains hydrogen, nitrogen and some other gases. It is used in immense quantities as a fuel and, after being enriched, for illuminating purposes, and is also burned to produce lamp black. The United States is almost the sole commercial producer of natural gas. In 1902 it is estimated that more than two hundred billion cubic feet were produced, valued at $30,867,668 § and replacing more than ten million tons of coal. Pennsylvania, Indiana, West Virginia and Ohio are the chief producing states.

PETROLEUM.

Petroleum is a liquid hydrocarbon obtained from wells or borings in the regions where it occurs. It varies widely in its nature and composition from a light easily flowing liquid to thick viscous oils used directly for lubricating purposes. It is usually of a dark brown or greenish color and has a distinct fluorescence which is seen not only in the crude oil but also in most of the liquids manufactured from it. The greater part of the American

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* *Mineral Industry*, 1902.

† *Engineering and Mining Journal*, 1904, p. 5.

‡ *Mineral Resources*, 1902, p. 977.

§ *Mineral Resources of the U. S.*, 1902, p. 634.

output consists essentially of hydrocarbons of the paraffine series C_nH_{2n+2} with smaller amounts of the series C_nH_{2n} and C_nH_{2n-6}. The Russian oil, obtained mainly from Baku, on the Caspian, is distinctly different in character, consisting mainly of the naphthenes C_nH_{2n} and does not yield nearly so much illuminating oil on distillation.

The production of crude petroleum in the United States in 1902 was 88,766,916 barrels; * Ohio, Texas, California, West Virginia, Pennsylvania and Indiana were the greatest producers and in the order named. Russia produced almost as great an amount but of a much less value.

Large amounts of petroleum are used in the crude state as a fuel and a smaller amount of special oils for lubricating purposes. Its chief value is due to its distillation products, mainly kerosene. Other valuable products arising from distillation of this crude oil are gasoline, naphtha, benzene. Various products such as lubricating oils, vaseline and paraffine are made from the residuum after the burning oils have been distilled off.

ASPHALTS AND BITUMENS.

Under this head may be included the true ASPHALT of the famous pitch lakes of Trinidad and of Bermudez, Venezuela; the MANJAK of Barbadoes; the elastic ELATERITE of Derbyshire, England; the ALBERTITE of New Brunswick; the GILSONITE of Utah, etc. Besides these sandstone and limestone impregnated with asphalt occur in Kentucky, California, Utah, Texas, Colorado, Indian Territory and other states and are mined and ground direct for pavements. The above names designate rather indefinite mixtures of hydrocarbons and their oxidized products. They are generally black in color, have a pitch-like lustre and burn easily with a pitchy odor. They vary from thick highly viscous liquids to solids and are slightly heavier than water.

The principal use is for street pavements, usually mixed with 70 to 80 per cent. of sharp sand, 5 to 15 per cent. of limestone, and a little coal-tar residuum. They are also used as cement, roofing and floor material, and as a paint for coating wood or metal to prevent decay or rust. They are used in large quantities for insulating electric wires, and are added as an adulterant and coloring material in rubber goods. They are important for water proofing

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* *Mineral Resources of the U. S.*, 1902, p. 536.

purposes both on wood and metal. Manjak and Gilsonite are important constituents of black varnishes.

The residue known as "malta" resulting from the distillation of some forms of petroleum is much like asphalt in its characteristics and composition and is generally included in trade summaries. The domestic production of asphalt and asphaltic rock was 105,458 tons in 1902 and 146,883 tons were imported.*

Fossil Resins.

The fossil resins amber, or succinite, copal and dammar do not occur in the United States. They are oxidized hydrocarbons much resembling ordinary resin in appearance.

AMBER, or succinite, is a fossil resin found chiefly along the Prussian coast of the Baltic Sea. It is usually transparent and of a yellowish or brownish color. Its chief use is for jewelry and for mouth pieces of pipes. It is also used in some special varnishes.

COPAL is dug by the natives from the soil on both the east and west coasts of Africa. It is soluble with difficulty in alcohol and turpentine and is very valuable for varnishes. It is too hard to be scratched by the nail.

DAMMAR is obtained both as a true resin exuding from trees and as a fossil gum. It is derived from the East Indies, the Moluccas and from New Zealand. It is not so hard as copal but is harder than resin. It is a valuable basic constituent of varnishes. The New Zealand dammar is almost wholly fossil.

Mineral Waxes.

OZOCERITE or mineral wax is essentially a paraffin, colorless to white when pure, but oftener greenish or brown, and possessing all the properties of beeswax except its stickiness. It is found in Galicia, Moldavia, and Utah, and is extensively used. In the crude state it serves as an insulator for electric wires. By distilling it yields: a refined product, ceresine, used for candles, waxed paper and hydrofluoric acid bottles; burning oils; paraffine; a product with properties and appearance of vaseline; and a black residuum which in combination with india rubber constitutes the insulating material called okonite.

In 1902 over 4000 tons were mined in Hungary.

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* *Mineral Resources of the U. S.*, 1902, p. 659.

Mineral Coal.

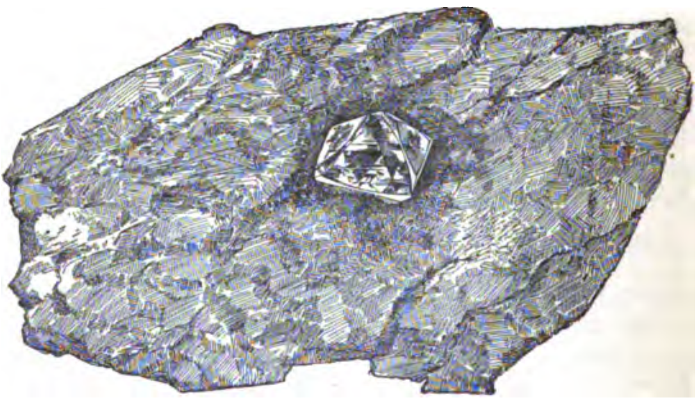
Mineral coal, excluding peat and lignite which retain the woody structure, is compact massive material produced by a gradual alteration of organic deposits chiefly vegetable. Bituminous, or soft coal, which retains a large amount of volatile matter readily converted by heat into gases, was mined to the extent of 283,406,691 tons in this country in 1903.* Anthracite, or hard coal, which contains little volatile matter, was produced during the same year to the amount of 73,390,000 tons. Nearly one-half of our total output of coal is mined in Pennsylvania. The United States now produces about one-third of the coal of the world.

DIAMOND.

COMPOSITION. — C.

GENERAL DESCRIPTION. — Transparent, rounded, isometric crystals with a peculiar adamantine lustre like oiled glass. Usually colorless or yellow, and with easy octahedral cleavage. Also translucent, rough, rounded crystalline aggregates and opaque

FIG. 491.



Diamond in Matrix, De Beer's Mine, Kimberley, S. A. Tiffany & Co.

crystalline or compact masses of gray to black color and no distinct cleavage. Especially characterized by a hardness exceeding that of any other known substance.

CRYSTALLIZATION. — Isometric. Hextetrahedral class, p. 56. Octahedra, often showing inverted triangular depressions, see Fig.

* *Engineering and Mining Journal*, 1904, p. 4.

† *Ibid.*

491, and hextetrahedral modifying faces are most common, while rounded hexoctahedra and, more rarely, cubes and other forms occur. Frequently twinned parallel to the octahedron. Index of refraction for yellow light 2.4195.

Physical Characters. H., 10. Sp. gr., 3.15 to 3.52.

LUSTRE, adamantine. TRANSPARENT to opaque.

STREAK, colorless. TENACITY, brittle.

COLOR, colorless, yellow, rose, green, blue, gray, black.

CLEAVAGE, octahedral.

BEFORE BLOWPIPE, ETC.—Is slowly consumed, producing its equivalent of carbon dioxide. In powder it is burned by ordinary blowpipe flame. Insoluble in acids.

VARIETIES.—*Carbonado or Black Diamond.*—Opaque, dark-colored, and without cleavage. Sp. gr., 3.15 to 3.29.

Bort.—Translucent, non-cleavable, crystalline aggregates, often harder than the crystals and more tough. Sp. gr., 3.499 to 3.503. The name bort is also applied to fragments of crystals.

REMARKS.—Origin not known. The diamond is found in alluvial deposits with other minerals, such as gold, platinum, zircon. The great South African localities, however, while in part alluvial or "river diggings," are chiefly confined to a limited area where they occur enclosed in a wall of carbonaceous shale surrounding a serpentine shale core, in which are found not only the diamonds, but garnets, zircon magnetite, etc. Diamonds have also been found in quartzose conglomerates and with the so-called flexible sandstone "itacolumite."

Although diamonds have been found in isolated localities in the southern and western States no deposits, not even of an alluvial character, have been discovered in North America. By far the largest diamond deposit ever found occurs at Kimberley, South Africa, and immense quantities are mined here annually. New and promising deposits have been opened recently near Pretoria, Transvaal. Alluvial deposits occur in Brazil, India, the Urals and Borneo.

USES. — As a gem when transparent and without flaw; colorless stones and those of decided tints ranking superior to yellow or brownish stones. Smaller stones, especially the translucent and opaque sort, are used in diamond drills, saws, and other cutting machinery, on account of their great abrasive power. The dust is also used in polishing other diamonds.

GRAPHITE. — Plumbago, Black Lead.

COMPOSITION.—C. Sometimes with iron, sand, clay, etc.

GENERAL DESCRIPTION.—Disseminated flakes or scaly to compact masses, and more rarely six-sided plates. Soft, greasy and cold to the touch; black to very dark gray in color and usually metallic in lustre. When impure it is apt to be slaty or earthy.

Physical Characters. H., 1 to 2. Sp. gr., 2.09 to 2.25.

LUSTRE, metallic to dull.	OPAQUE.
STREAK, dark-gray.	TENACITY, scales flexible, slightly sectile.
COLOR, black or dark gray.	
CLEAVAGE, basal, cleaves into plates.	UNCTUOUS, marks paper.

BEFORE BLOWPIPE, ETC.—Infusible, but is gradually burned. May react, if impure, for water, iron and sulphur. Insoluble in acids. If a piece of graphite is brought into contact with a piece of zinc in a solution of copper sulphate, it is quickly copper-plated. Molybdenite under the same test is very slowly plated.

SIMILAR SPECIES.—Differs from molybdénite in darker color, streak, flame test and salt of phosphorus bead, and as above mentioned. Micaceous hematite is harder and has a red streak.

REMARKS.—Graphite probably results from alteration of embedded organic matter coal, peat, etc., by heat, destructive distillation and pressure. It occurs disseminated in crystalline limestones and granites and in larger irregular masses. Large deposits exist in Ceylon, Austria and Eastern Siberia. Almost all the American output is obtained at Ticonderoga, N. Y. Deposits at Southampton, Pa., and near Raleigh, N. C., have also produced graphite in commercial quantities.

USES.—Graphite is used for refractory vessels, as crucibles, retorts, stove polish, etc., for lead pencils, in electroplating, in electrical supplies, in casting moulds, as a finish, as a lubricant for machinery, as a paint for iron, etc., for coating metals, shot, gunpowder, etc. Artificial graphite of excellent quality is now made at Niagara Falls from anthracite coal in electric furnaces.

CHAPTER XXXVI.

SILICA AND THE SILICATES.

THE minerals composed of silica alone and the silicates cannot conveniently be classified upon an economic basis, and we have, therefore, followed practically the order of Dana's "System of Mineralogy," Sixth Edition, believing that—in this country, at least—most collections of minerals will be arranged in this order for many years. The order herein followed is:

A.—SILICA.

B.—ANHYDROUS SILICATES:

- I. Disilicates and Polysilicates.
- II. Metasilicates.
- III. Orthosilicates.
- IV. Subsilicates.

C.—HYDROUS SILICATES:

- I. Zeolite Division.
- II. Mica Division.
- III. Serpentine and Talc Division.
- IV. Kaolin Division.

D.—TITANO SILICATES.

ECONOMIC DISCUSSION.

Aside from the occasional occurrence of certain silicates in specimens suitable for gems, only a few of this greatest group of common minerals are of economic importance as distinct minerals. The great stone or quarry industry,* however, which represents in the United States a capital of over $100,000,000, and produced in 1902 material worth in the rough over $64,000,000, consists in the extraction of blocks of either limestone and marble or of silica and silicates. For instance, in 1902 the values of materials quarried in this country were:

* The facts and figures, where given for the year 1902, are taken from *Mineral Resources of the U. S.*, 1902.

Granite	$18,257,944
Sandstone	9,437,646
Bluestone	1,164,481
Slate	5,696,051

The amount of stone used in building in this country in 1902 was approximately of the value of $21,000,000.

GRANITE, commercially speaking, includes a number of hard, durable rocks, such as granite proper, syenite, gneiss, basalt, diorite, and andesite, which are composed of silicates — usually three or more — and principally quartz, the feldspars and the micas, pyroxene and amphibole. It is used in enormous quantities in buildings, in paving blocks and in construction of bridges and dams. In 1902, granite to the value of $18,257,944 was quarried in the United States, of which $5,660,129 worth was used in building and the balance in paving blocks, monumental work, flagstones and curbstones, crushed stone, etc.

SANDSTONE is composed of grains, chiefly quartz, with sometimes a little feldspar, mica or other minerals, and is classified as siliceous, ferruginous, calcareous or argillaceous, according to the nature of the cement which binds the grains together. Its uses are the same as those of granite, but a larger proportion of the quantity quarried is used in building. In 1902, sandstone to the value of $9,437,646 was quarried in the United States.

BLUESTONE is a very hard, durable, fine-grained sandstone, cemented together with siliceous material. It is used principally for flag and curb stone. In 1902, bluestone to the value of $1,164,481 was quarried in the United States.

SLATE is used chiefly as roofing material and for interior work, such as blackboards, table tops, sinks, etc. Slate and slate manufactures to the amount of $5,696,051, were produced in the United States in 1902, and 4,071 tons of slate and shale were ground for mineral paint.

FIBROUS TALC and compact talc, or soapstone, are extensively used, the former for grinding to "mineral pulp," used in paper manufacture, the latter for many purposes, usually because it is refractory, expands and contracts very little, retains heat well and is not attacked by acids. These properties make it valuable in furnaces, crucibles, sinks, baths, hearths, electrical switch boards and cooking utensils. Talc is also used in cosmetics, refractory paints, slate pencils, crayons, gas tips, as a lubricant and in soap making.

In 1902 there were produced in this country 71,100 tons of fibrous talc and 26,854 tonsof soapstone.

THE MICAS, muscovite, phlogopite and biotite, have become of great importance as non-conductors in electrical apparatus, and are also used in stove and furnace doors. The larger sheets are cut and split to the desired size; the waste is, to some extent, built up into plates suitable for certain grades of electrical work, and for covering steam boilers and pipes. Large amounts of formerly wasted material are now ground and used for decorative interior work, to ornament porcelain and glassware, to spangle wall paper, in calico printing, as a lubricant and more recently as an absorbent of nitro-glycerine and in the manufacture of certain smokeless powders.

Sheet mica to the amount of 373,266 pounds was produced in this country in 1902 and 1,400 tons of scrap mica were ground.

ASBESTOS. — The minerals amphibole and serpentine, in their fibrous varieties, are known commercially as asbestos, and are extensively used as incombustible paper, cloth, cement, boiler and steam-pipe covering, yarn or rope for packing valves. Only 1,005 tons were obtained in 1902 in the United States. The large supply coming from Canada and Italy is the fibrous serpentine, chrysotile.

SERPENTINE is, to some extent, mined and used as an ornamental stone, but is commercially classed with the marbles.

FELDSPAR is crushed in large quantities for admixture with kaolin in the manufacture of porcelain. In the United States 45,287 tons were produced in 1902.

QUARTZ is used in large amounts in the manufacture of sandpaper, porcelain, glass, honestones, oilstones, and as a flux. Its colored and chalcedonic varieties are used as semi-precious or ornamental stones. In 1902 the United States produced over 1,000,000 long tons of quartz and quartz sand. Ground flint, which is included under this head, is used as a scouring powder in soaps as well as for the other purposes mentioned.

INFUSORIAL EARTH is calcined and made into water filters, polishing powders, soap filling and boiler and steam-pipe covering.

KAOLINITE AND CLAY. — Enormous and varied industries use as their raw material the beds of clay which result from the decomposition of the feldspars and other silicates. These beds are composed in part of some hydrous aluminum silicate such as kaolinite, but usually with intermixed quartz, mica, undecomposed feldspar,

oxides and sulphides of iron. Their properties and uses depend chiefly upon their composition. Brick, tile and pottery to the amount of $122,169,531 were manufactured in 1902 in the United States.

The clay industries include the manufacture of common brick, paving brick, fire-brick, and hydraulic cement, all varieties of earthenware, stoneware and porcelain, terra cotta, sewer pipes and drain tiles, and are carried on all over the country and the world.

FULLERS EARTH, a kind of clay, was mined in Florida to the extent of 11,492 tons in 1902, and used in the refining and clarifying of mineral oils. Several thousand tons are imported from England for bleaching lard and cottonseed oils.

GARNETS to the amount of 3926 tons were ground for abrasives in 1902.

GEMS. — The minerals beryl, garnet, topaz, tourmaline, spodumene, titanite and chrysolite are sometimes found in specimens which are valuable as gems.

SILICA.

The minerals composed of silica (SiO_2) are:

Quartz	SiO_2	Hexagonal
Tridymite	SiO_2	Hexagonal
Opal	$SiO_2.nH_2O$	

QUARTZ. — Agate, Jasper, Chalcedony.

COMPOSITION. — SiO_2, (Si 46.7, O 53.3 per cent.).

GENERAL DESCRIPTION. — A hard, brittle mineral which is best known in transparent, glassy, hexagonal crystals, and as the some-

FIG. 492.

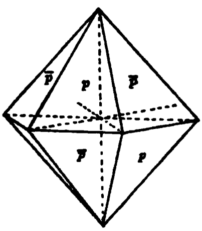


FIG. 493.

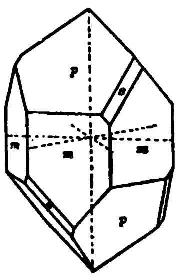
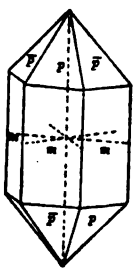


FIG. 494.



what greasy lustred, shapeless, transparent mineral of granite and other igneous rocks. Crystals frequently occur white, amethyst, smoky and red. Translucent, wax-like, non-crystalline

layers of gray, yellowish and bluish tints are often found in cavities with usually a mammillary or botryoidal structure. It is also found as nearly opaque, non-crystallized material containing con-

FIG. 495.

Smoky Quartz. N. Y. State Museum.

siderable amounts of iron, and alumina, and often highly colored, as red, brown, or yellow.

CRYSTALLIZATION. — Hexagonal. Class of trigonal trapezohedron, p. 49. Axis $\dot{c} = 1.0999$. Usually a combination of unit

FIG. 496.

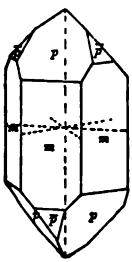


FIG. 497.

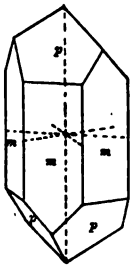


FIG. 498.

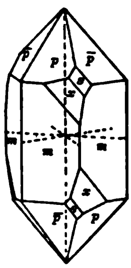
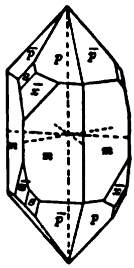


FIG. 499.



prism m with one or both unit rhombohedra, p and $\bar{p}$, the former often larger and brighter, and the prism faces nearly always horizontally striated. The second order pyramid $s = (2a : 2a : a : 2c)$; $\{11\bar{2}1\}$; frequently occurs and rarely the trapezohedral faces

$x = (\frac{6}{5}a : 6a : a : 6c)$, $\{51\bar{6}1\}$; either right, Fig. 498, or left, Fig. 499. Supplement angles $pp = 85° 46'$; $mp = 38° 13'$; $ms = 37° 58'$; $mx = 12° 1'$.

Twinned crystals are not rare. See page 65.

Optically +. With low refraction and weak double refraction ($\alpha = 1.544$; $\gamma = 1.553$ for yellow light). Circularly polarizing. Basal sections 1 mm. thickness turn the plane of polarization for yellow light 21.7° to right or left.

Physical Characters. H., 7. Sp. Gr., 2.6 to 2.66.

LUSTRE, vitreous to greasy. TRANSPARENT to opaque.
STREAK, white. TENACITY, brittle to tough.
COLOR, colorless and all colors.
CLEAVAGE, difficult, parallel to rhombohedron.

BEFORE BLOWPIPE, ETC.—Infusible. With soda, fuses with marked effervescence to a clear or opaque bead, according to the proportions used. Insoluble in salt of phosphorus and slowly soluble in borax. Insoluble in all acids except hydrofluoric.

VARIETIES.

A. CRYSTALLINE VARIETIES.—Vitreous in lustre, often transparent; occurring in isolated or grouped crystals or drusy surfaces or crystalline.

Rock Crystal.—Pure, colorless or nearly colorless quartz.

Amethyst.—Purple to violet and shading to white. Fracture shows lines like those of the palm of the hand. Color disappears on heating, and is probably due to a little manganese.

Rose Quartz.—Light-pink or rose-red, becoming paler on long exposure to light. Usually massive. Colored by titanium or manganese.

Yellow Quartz or *False Topaz.*—Light yellow.

Smoky Quartz.—Dark yellow to black. Smoky tint, due to some carbon compound.

Milky Quartz or *Greasy Quartz.*—Translucent. Usually massive. Common as a rock constituent.

Ferruginous Quartz.—Opaque, brown or red crystals, sometimes small and cemented like a sandstone.

Aventurine.—Spangled with scales of mica, hematite, or goethite.

Cat's Eye.—Opalescent, grayish-brown or green quartz with included parallel fibres of asbestus.

B. Chalcedonic Varieties.—With lustre like wax. Translucent. Not in crystals. Frequently nodular, mammillary, stalactitic or filling cavities.

Chalcedony.—Pale blue or gray varieties, uniform in tint.

Agate.—Strata or bands representing successive periods of deposition, and frequently of different tints or with irregularly mingled colors or visible colored inclusions constituting such sub-varieties as *banded agate, clouded agate, moss agate, ruin or fortification agate, etc.*

Carnelian or Sard.—Blood-red or brownish-red.

Onyx and Sardonyx.—Parallel layers of lighter and darker color, as white and black, white and red, etc. The layers are in planes.

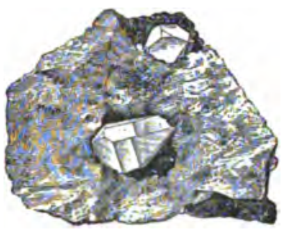
Chrysoprase.—Apple-green.

Prase.—Dull leek-green.

Plasma, Heliotrope and Bloodstone. Bright to dark-green, spotted with white or red dots.

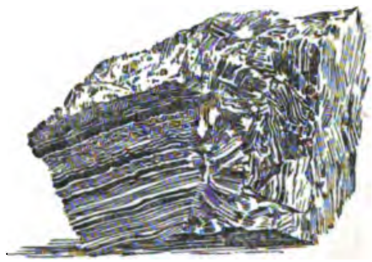
C. Jasper Varieties.—Opaque, dull in lustre, usually high in color, impure from clay and iron.

Fig. 500.



Herkimer Co., N. Y.

Fig. 501.



Agate. Schlottwitz, Saxony.

D. In addition to these, there are

Flint.—Smoky-gray to nearly black, translucent nodules, found in chalk-beds.

Touchstone.—Velvet-black and opaque, on which metal streaks are easily made and compared.

Sandstones.—Quartz grains cemented by silica, iron oxide, clay, calcium carbonate, etc.

Quartzite, compact quartz, granular or slaty in structure.

Remarks.—Quartz is chiefly found as an original constituent of such rocks as granite, gneiss, etc, formed by igneous or plutonic action, and also, to a very large extent, as a deposit from solution in water. Silicates are attacked by carbonated

waters, forming carbonates of calcium, magnesium, sodium, etc., and leaving a residue of silica. This, in turn, is soluble in hot solutions of these same carbonates, and is dissolved, transported, and, by evaporation and cooling, is redeposited, filling seams, cavities, veins, etc. Quartz is the most common of all solid minerals, and occurs with almost all other species and in almost all localities.

USES.—Aside from the uses of the quartz rocks in building, etc., large quantities of quartz are used in the manufacture of sand-paper, glass, porcelain and as an acid flux in smelting. The chalcedonic varieties—agate, onyx, etc.—are often polished and used as ornaments, and so also are some of the jaspers. Rock crystal is used in cheap jewelry, and is cut for spectacles and for some forms of optical apparatus. The colored crystalline varieties are often cut in cheap jewelry, and the amethyst, when of a particular dark purple, is highly valued as a gem.

TRIDYMITE.

COMPOSITION.—SiO_2.

GENERAL DESCRIPTION.—Small colorless, six sided plates. Often in wedge-shaped groups of three (trillings), which are sometimes octahedral in appearance.

PHYSICAL CHARACTERS.—Transparent. Lustre, vitreous. Color, colorless or white. Streak, white. H., 7. Sp. gr., 2.28 to 2.33. Brittle.

BEFORE BLOWPIPE, ETC.—Like quartz, but soluble in boiling sodium carbonate.

REMARKS.—Occurs in cavities in volcanic rocks, such as trachyte or andesyte.

OPAL.

COMPOSITION.—$SiO_2.nH_2O$, (H_2O, 5 to 12 per cent.).

GENERAL DESCRIPTION.—Transparent to translucent veins and masses, usually of milky-white or red color and frequently showing blue, green, red, etc., internal reflections (opalescence). This grades into less translucent and opaque masses, with no play of color and somewhat resembling chalcedony, but without the wax-like lustre. Other varieties are transparent, like melted glass, and opaque and earthy.

Physical Characters. H., 5.5 to 6.5. Sp. gr., 2.1 to 2.2.

LUSTRE, vitreous, pearly, dull.	TRANSPARENT to opaque.
STREAK, white.	TENACITY, brittle.
Color, colorless and all colors.	

BEFORE BLOWPIPE, ETC.—Infusible. Becomes opaque and yields more or less water. Soluble in hydrofluoric acid more easily than quartz and soluble in caustic alkalies.

VARIETIES.

Precious Opal.—Milky-blue, yellow or white translucent material with fine internal reflections, attributed to thin curved lamellæ, which have been cracked, bent and broken during solidification.

Fire Opal.—Reddish or brown in color and with reflections having the appearance of fire.

Common or Semi-Opal.—Translucent to opaque, with greasy lustre and of all colors, but without opalescence. Most frequently yellow or brown.

Wood Opal—Petrified wood, the petrifying material being opal.

Opal Jasper.—Like ordinary jasper, but with resinous lustre.

Hyalite.—Colorless transparent masses resembling drops of melted glass or of gum arabic.

Geyserite, Siliceous Sinter.—Loose, porous rock of opal silica deposited from hot water. Opaque, brittle and often in stalactitic or other imitative shapes.

Fiorite or Pearl Sinter.—Pearly, translucent material found in volcanic tufa and near hot springs.

Tripolite or Infusorial Earth.—Massive, chalk-like or clay-like material composed of the remains of diatoms.

SIMILAR SPECIES.—Softer than quartz and soluble in caustic alkalies. May also yield noticeable water in a closed tube. Rarely confused with any other mineral.

REMARKS.—Occurs in fissures in igneous rocks or imbedded in limestone, clay-beds, etc. Fine precious opals are found at Gem City, Washington; at Opaline, Idaho; also in Latah County, Idaho, and Morrow County, Washington. Queretaro and Zimapan, Mexico, also yield good gems. Other famous localities are Czerwenitza, Hungary; Bula Creek, Queensland, and Wilcannia, New South Wales. Deposits of infusorial earth occur at Dunkirk, Md.; Richmond, Va.; Virginia City, Mo., also in Connecticut, New Hampshire, New Jersey and California. All of these deposits have been worked, but not continuously.

USES.—Precious and fire opals are beautiful gems. Opalized wood is cut and polished for ornament. Tripolite has many uses; *e.g.*, polishing and washing powders, lagging for boilers, cement, soluble glass, and as the dope in dynamite.

POLYSILICATES.

The POLYSILICATES may be derivatives of $H_2Si_2O_5$, $H_6Si_2O_7$, $H_4Si_3O_8$, and possibly other more complicated silicic acids, or they may be formed by isomorphic mixtures of salts of these

acids with each other or with the orthosilicates or metasilicates. Many of the polysilicates are so variable and so complex that it is impossible to express their composition by formula, and many others are designated by formulæ which are, at the best, but approximations. Under this head comes Petalite, a derivative of $H_2Si_2O_5$, and the important subdivision of the FELDSPARS, derivatives of $H_4Si_3O_8$ and of fairly definite composition.

PETALITE.

COMPOSITION.—$LiAl(Si_2O_5)_2$.

GENERAL DESCRIPTION.—Glassy white or gray foliated and cleavable masses and rarely minute, colorless crystals, like pyroxene in form.

PHYSICAL CHARACTERS.—Transparent to translucent. Lustre, vitreous. Color, colorless, white, gray, occasionally pink. Streak, white. H., 6 to 6.5. Sp. gr., 2.39 to 2.46.

BEFORE BLOWPIPE, ETC.—Phosphoresces with gentle heat; with strong heat, whitens and fuses on the edges and colors the flame carmine. Insoluble in acids.

THE FELDSPARS.

These are of great importance as rock-forming minerals and have a close resemblance in many characters; *e.g.*:

Very similar in crystalline form. System either monoclinic or triclinic. Prism angles nearly 120°; many of the other angles closely agreeing.

Two prominent cleavages inclined at or near 90°.

Hardness, 6 to 6.5.

Specific gravity, generally between 2.55 and 2.75.

Composition, $R'AlSi_3O_8$ or $R''Al_2Si_2O_8$, or isomorphic mixtures of these.

The feldspars here described are:

Orthoclase	$KAlSi_3O_8$	Monoclinic
Microcline	$KAlSi_3O_8$	Triclinic
Plagioclase	$m(NaAlSi_3O_8) + n(CaAl_2Si_2O_8)$	Triclinic

ORTHOCLASE.—Feldspar, Potash Feldspar.

COMPOSITION.—$KAlSi_3O_8$, with some replacement by Na.

GENERAL DESCRIPTION.—Cleavable masses, showing angle of 90; and monoclinic crystals, of flesh-red, yellow or white color. Also compact, non-cleavable masses, resembling jasper or flint. Sometimes colorless grains or crystals.

CRYSTALLIZATION. — Monoclinic. Axes $\beta = 63° 57'$; $\grave{a} : \bar{b} : c = 0.659 : 1 : 0.555$. Most frequent forms: unit prism m, pina-

coids b and c and positive orthodomes $o = (\grave{a} : \infty \bar{b} : c)$; $\{101\}$; and $y = (\grave{a} : \infty b : 2c)$; $\{201\}$. Supplement angles are: $mm = 61° \; 13'$; $cm = 67° \; 47'$; $co = 50° \; 17'$; $cy = 80° \; 18'$.

Twin forms of Carlsbad type, Fig. 506, twin plane the ortho pinacoid, are very common; the Baveno type, Fig. 507, twin plane a clino dome, and Mannebacher type, twin plane the base c, Fig. 508, are less common.

FIG. 502.

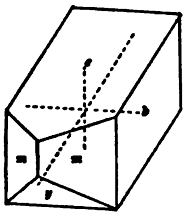


FIG. 503.

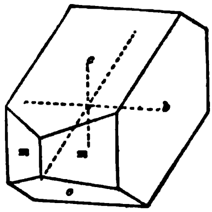


FIG. 504.

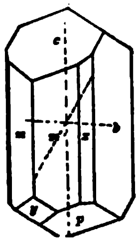


FIG. 505.

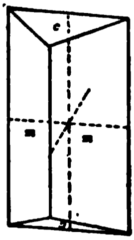


FIG. 506.

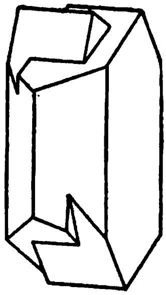


FIG. 507.

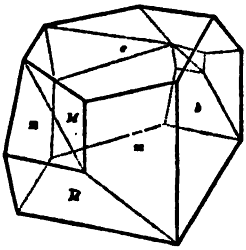
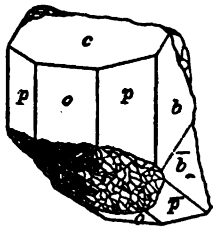


FIG. 508.



Optically —, with weak refraction and double refraction. Axial plane usually normal to b. In thin sections rarely shows multiple twinning and is usually turbid from kaolin.

Physical Characters. H., 6 to 6.5. Sp. gr., 2.44 to 2.62.

LUSTRE, vitreous or pearly. TRANSPARENT to opaque.

STREAK, white. TENACITY, brittle.

COLOR, flesh-red, yellowish, white, colorless, gray, green. CLEAVAGE, parallel to c and b, hence at right angles.

BEFORE BLOWPIPE, ETC. — Fuses in thin splinters to a semi-transparent glass and colors the flame violet. Insoluble in acids.

VARIETIES.

Ordinary. — Simple or twinned crystals, sometimes of great size,

of nearly opaque pale red, pale yellow, white or green color. More frequently imperfectly formed crystals and cleavable masses, in the granitic rocks.

Adularia. — Colorless to white, transparent, often opalescent. Usually in crystals.

Sanidine and Rhyacolite. — Glassy, white or colorless crystals in lava, trachyte, etc.

Loxoclase. — Grayish-white or yellowish crystals, which have a tendency to cleave parallel to the ortho pinacoid.

Felsite. — Jaspery or flint-like masses of red or brown color.

SIMILAR SPECIES. — Differs from the other feldspars in the cleavage at 90°, the greater difficulty of fusion, the absence of striations, etc.

REMARKS. — Usually of igneous origin, sometimes secondary. With mica and quartz it forms the important rocks granite, gneiss, and mica schist, and is also the basis of syenite, trachyte, porphyry, etc. It changes to kaolin quartz, opal, epidote and muscovite, by the removal of bases through the action of acid waters. Orthoclase is quarried at South Glastonbury and Middletown, Conn.; Edgecomb and Brunswick, Me.; Chester, Mass.; Brandywine Summit, Pa.; Tarrytown and Fort Ann, N. Y.

USES. — It is one of the constituents of porcelain and chinaware, chiefly to form the glaze, but partly mixed with the kaolin and quartz in the body of the ware.

MICROCLINE.

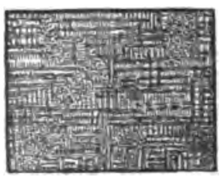
COMPOSITION. — $KAlSi_3O_8$.

GENERAL DESCRIPTION. — Like orthoclase, except that the macro axis is at 89° 30′ to the vertical instead of 90°, and the basal cleavage often shows fine striations. In thin basal sections between crossed nicols it shows a peculiar interlaced structure due to two series of twin lamellæ which cross nearly at right angles as in Fig. 510.

FIG. 509.

Microcline, Pike's Peak, Colorado, Foote Mineral Co.

FIG. 510.



Microcline Basal Section between Crossed Nicols.

Optically —. Axial plane nearly normal to the brachy-pinacoid. The extinction angle on a basal section is + 15° 30′, while that of orthoclase is 0°.

PHYSICAL CHARACTERS. — Essentially as in orthoclase. Sp. gr. 2.54 to 2.57, and cleavage at 89° 30′ instead of 90°.

BEFORE BLOWPIPE, ETC. — As for orthoclase.

REMARKS. — Includes varieties, amazon stone, perthite, chesterlite, etc., formerly grouped under orthoclase. Often interlaminated with albite or orthoclase.

Anorthoclase. — A triclinic sodium-potassium feldspar found mainly in the lavas of Pantellaria. Color, lustre and hardness the same as for other feldspars. Cleavage close to 90°. Sp. gr. 2.59. Distinguished by its optical characters.

PLAGIOCLASE. — Albite, Anorthite, Oligoclase, Labradorite.

The name "*plagioclase*" was originally given to minerals closely resembling common feldspar in cleavage, crystal form, mode of occurrence, hardness, specific gravity and other physical characters, but with the angle between the two cleavages about 86° instead of 90°. The very great variations in composition led to the establishment of several species, in which, however, the variations in composition were still great, and finally to a theory, now generally accepted, which may be expressed as follows: *The plagioclases consist of isomorphous mixtures of two (or three) triclinic compounds, $NaAlSi_3O_8$ and $CaAl_2Si_2O_8$ (and $KAlSi_3O_8$). Some specimens approach the end members, and are then called respectively albite, anorthite (and microcline), but, in general, distinct species cannot be said to exist.*

In accordance with this, the more prominent species names are here given as varieties of the group name PLAGIOCLASE.

COMPOSITION. — $m(NaAlSi_3O_8) + n(CaAl_2Si_2O_8)$, with some replacement by $KAlSi_3O_8$.

GENERAL DESCRIPTION. — Granular masses or small triclinic crystals, or coarser masses. Each grain or crystal cleaves easily in two directions, which make an angle of about 86° with each other, and shows on one or both surfaces by reflected light the parallel "twin striations." Some varieties show marked play of colors, others the moonstone effect. Usually light colored, and most frequently colorless, white or faintly tinged, sometimes (labradorite) dark gray. Just about the hardness of a good knife.

CRYSTALLIZATION. — Triclinic, usually in crystals resembling that shown in Fig. 511, with supplement angles *mM* approximately 60°, and frequently twinned either by the albite law, twin plane

b, Fig. 512, which, if repeated, results in striations on *c*; or by the pericline law, twin axis the macro axis, Fig. 513, producing striations on *b*.

Albite and anorthite are frequently crystallized, the other varieties less frequently.

Optically shows weak refraction and double refraction. Low order gray interference colors. Thin sections with polarized light

FIG. 511.

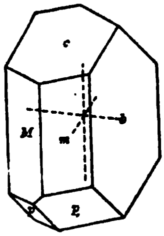


FIG. 512.

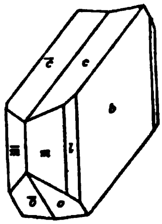
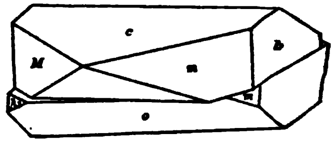


FIG. 513.



show parallel bands due to the twin lamellæ, and extinction angles characteristic of the variety.

Physical Characters. H., 5 to 7. Sp. gr., 2.6 to 2.7.

LUSTRE, vitreous or pearly. TRANSLUCENT to opaque.

STREAK, white. TENACITY, brittle.

COLOR, pure white, colorless or tinted by red or yellow. Sometimes dark gray or green.

CLEAVAGES, at angle of 86° approximately.

BEFORE BLOWPIPE, ETC. — Fuses with difficulty to a colorless glass or white enamel, and usually colors the flame yellow. In fine powder, is either slightly decomposed by hydrochloric acid or is insoluble.

VARIETIES.

Albite (Soda Feldspar, Pericline). — $NaAlSi_3O_8$. Usually pure white, often granular or with curved cleavage surfaces, and often in crystals (Figs. 511 to 513) in cavities in gneiss, mica schist and granite and other igneous rocks, especially those high in silica. Often encloses the rarer minerals, tourmaline, beryl, chrysoberyl, topaz, etc. Is the chief constituent of diorite. Not easily altered.

Anorthite (Lime Feldspar, Indianite). — $CaAl_2Si_2O_8$. Comparatively rare as a pure mineral. Best known in the small highly modified glassy crystals of Vesuvius and the larger white crystals

of Miyake, Japan, which frequently enclose grains of green chrysolite and are often covered with a black crust.

Oligoclase (Soda Lime Feldspar). — 2 to 6 $(NaAlSi_3O_8) + CaAl_2Si_2O_8$. Not rare, accompanying orthoclase as grayish white, translucent masses, with somewhat greasy lustre and marked twin striations. Occurs also as reddish cleavable masses, sunstone, and rarely as crystals.

Labradorite (Lime Soda Feldspar). — $NaAlSi_3O_8$ + 1 to $3(CaAl_2Si_2O_8)$. Usually dark gray cleavable masses often associated with hypersthene. Commonly iridescent, showing beautiful changing colors, blue, green and red, from inclusions of diallage, ilmenite or goethite. Striated like oligoclase. Occurs in the gabbros, dolerites and other basic rocks; but is notably absent in localities containing orthoclase and quartz. It alters readily to zeolites, calcite, datolite, etc. Found abundantly in the Adirondacks, N. Y., in the Wichita Mountains, Ark., in Quebec and in Labrador.

Other plagioclases of less importance are: *Andesite*, $NaAlSi_3O_8 + CaAl_2Si_2O_8$, *Bytownite*, $NaAlSi_3O_8 + 6(CaAl_2Si_2O_8)$, and *Oligoclase-Albite*, $6(NaAlSi_3O_8) + CaAl_2Si_2O_8$

USES. — The plagioclases have no important uses except as rock constituents and the limited use of the iridescent varieties for ornamental work (labradorite) or semi-precious stones (moonstone and sunstone).

THE METASILICATES.

The METASILICATES are derivatives of H_2SiO_3, and the most important are described in the following order:

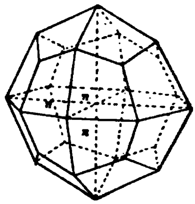
Leucite	$K.Al(SiO_3)_2$	Isometric
	PYROXENE GROUP.	
Enstatite	$(Mg.Fe)SiO_3$	Orthorhombic
Hypersthene	$(Mg.Fe)SiO_3$	Orthorhombic
Pyroxene	$(Ca.Mg.Mn.Fe.Al)SiO_3$	Monoclinic
Wollastonite	$CaSiO_3$	Monoclinic
Pectolite	$HNaCa_2(SiO_3)_3$	Monoclinic
Rhodonite	$MnSiO_3$	
Amphibole	$RSiO_3$	Monoclinic
Beryl	$BeAl_2(SiO_3)_6$	Hexagonal
Cyanite	$(AlO)_2SiO_3$	Triclinic

IOLITE, $Mg_3(AlFe)_6(SiO_4)_4(SiO_3)_4$, orthorhombic, is an intermediate species between metasilicates and orthosilicates.

Many of the hydrous silicates are also derivatives of metasilicic acid.

LEUCITE.

FIG. 514.



COMPOSITION.—$KAl(SiO_3)_2$.

GENERAL DESCRIPTION.—Gray, translucent to white and opaque, disseminated grains and trapezohedral crystals in volcanic rock.

CRYSTALLIZATION.—Isometric externally, but with polarized light, showing double refraction at all temperatures below 500° C.

Physical Characters. H., 5.5 to 6. Sp. gr., 2.45 to 2.50.
LUSTRE, vitreous to greasy, TRANSLUCENT to opaque.
STREAK, white. TENACITY, brittle.
COLOR, white or gray, or with yellowish or red tint.

BEFORE BLOWPIPE, ETC. Infusible. With cobalt solution, becomes blue. Soluble in hydrochloric acid, leaving a fine powder of silica.

REMARKS.—A constituent of lavas, sometimes the chief constituent. By alteration, changes to kaolin, mica, nephelite, orthoclase, quartz, etc. It is not common in America, but is found in the Leucite Hills, Wyoming, and also in the northwestern part of the same State. Very common in the Vesuvian lavas.

USES.—Leucite rock has long been used for millstones.

ENSTATITE.—Bronzite.

COMPOSITION.—(Mg.Fe) SiO_3.

GENERAL DESCRIPTION.—Brown to gray or green, lamellar or fibrous masses, with sometimes a peculiar metalloidal lustre (bronzite). Rarely in columnar orthorhombic crystals.

PHYSICAL CHARACTERS.—Translucent to opaque. Lustre, pearly, silky or metalloidal. Color, brown, green, gray, yellow. Streak, white. H., 5.5. Sp. gr., 3.1 to 3.3. Brittle.

BEFORE BLOWPIPE, ETC.—Fusible on the edges. Almost insoluble in acids. With cobalt solution is turned pink.

REMARKS.—It is rare in quartzose rocks, but occurs frequently in meteorites and with chrysolitic, basaltic and granular eruptive rocks. Occurs also associated with chondrodite, apatite, talc, etc. By alteration it forms serpentine, talc, and limonite.

HYPERSTHENE.

COMPOSITION —$(Mg.Fe)SiO_3$, with more iron than enstatite.

GENERAL DESCRIPTION.—Dark-green to black, foliated masses or rare orthorhombic crystals, which grade into enstatite. Frequently shows a peculiar iridescence, due to minute interspersed crystals.

PHYSICAL CHARACTERS.—Translucent to opaque. Lustre, pearly or metalloidal. Color, dark-green to black. Streak, gray. H., 5 to 6. Sp. gr., 3.4 to 3.5. Brittle.

BEFORE BLOWPIPE, ETC.—Fuses on coal to a black, magnetic mass. Partially soluble in hydrochloric acid.

REMARKS.—Hypersthene is common in certain granular eruptive rocks, gabbros, norites, etc

In thin sections hypersthene is often strongly pleochroic while enstatite is only weakly so. Hypersthene often also includes tabular brown scales.

BASTITE. — An alteration product of enstatite near serpentine in composition. It is usually foliated and of a yellowish or greenish color and has a peculiar bronze-like lustre on the cleavage surface. H., 3.5–4. Sp. gr., 2.5–2.7.

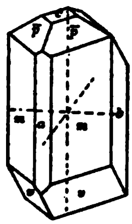
PYROXENE. — Augite.

COMPOSITION.—$RSiO_3$. R = Ca, Mg, Mn, Fe, Al, chiefly.

GENERAL DESCRIPTION.—Monoclinic crystals. Usually short and thick, with square or nearly square cross-section, or octagonal and with well-developed terminal planes. Granular, foliated and columnar masses and *rarely* fibrous Color, white, various shades of green, rarely bright green, and black.

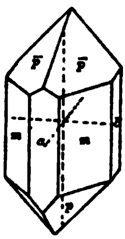
CRYSTALLIZATION.—Monoclinic. $\beta = 74° \ 10'$. Axes $\grave{a} : \bar{b} : \dot{c} = 1.092 : 1 : 0.589$.

FIG. 515.



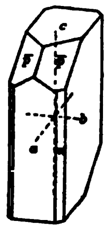
Diopside,
Pitcairn, N. Y.

FIG. 516.



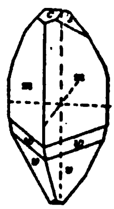
Rossie, N. Y.

FIG. 517.



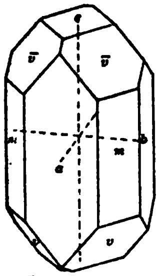
Diopside,
De Kalb, N. Y.

FIG. 518.



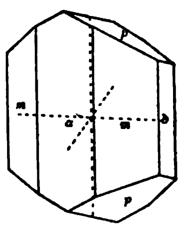
Fassaite.

FIG. 519.



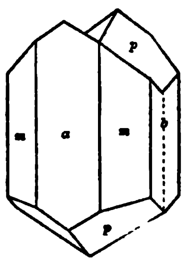
Leucaugite,
Sing Sing, N. Y.

FIG. 520.



Augite.

FIG. 521.



Augite twin.

Common forms: unit prism m, the pinacoids a, b and c, the negative and, more rarely, the positive unit pyramids $\bar{p}$ and p, the negative and positive pyramids $\bar{v}$ and $v = (\grave{a} : \bar{b} : 2c)$; $\{221\}$. Supplement angles are: $mm = 92° 50'$; $\bar{p}\bar{p} = 48° 29'$; $pp = 59° 11'$; $\bar{v}\bar{v} = 68° 42'$; $vv = 84° 12'$; $c\bar{p} = 33° 49'$; $cp = 42° 2'$; $c\bar{v} = 49° 54'$; $cv = 65° 21'$.

Contact twins, twinning plane a, Fig. 521, are common. Also twin lamellæ parallel c, shown by striations on the vertical faces and by basal parting. Optically +. Axial plane b. Strong double refraction. Varying axial angle. Usually not strongly pleochroic.

Physical Characters. H., 5 to 6. Sp. gr., 3.2 to 3.6.

LUSTRE, vitreous, dull or resinous. OPAQUE to transparent.
STREAK, white to greenish. TENACITY, brittle.
COLOR, white, green, black, brown.
CLEAVAGE, prismatic (angle 87° 10').

BEFORE BLOWPIPE, ETC.—Variable. Usually fuses easily to dark glass, sometimes to magnetic globule. Not generally soluble in acids.

VARIETIES.

Malacolite or Diopside.—$CaMg(SiO_3)_2$. Usually white or pale-green.

Hedenbergite.—$(Ca.Fe)(SiO_3)_2$. Grayish-green.

Augite.—Chiefly $CaMg(SiO_3)_2$, but containing also Al and Fe. Dark-green to black, and many others which grade into each other imperceptibly.

Diallage.—Thin foliated pyroxene, green or brown in color.

SIMILAR SPECIES.—Differs from amphibole, as therein described.

REMARKS.—Next to the feldspars, pyroxene is the most common constituent of igneous rocks. It occurs also in crystalline limestones and dolomites, and usually of some light-green or white color (diopside). In serpentine it is apt to be lamellar diallage. In granite it is usually green, and in eruptive rocks is dark-green or black augite. It alters to chlorite, serpentine, amphibole, etc.

Acmite. — $NaFe(SiO_3)_2$ occurs in prismatic or needle crystals of dark green or dark brown color. It is strongly pleochroic.

Jadeite. — $NaAl(SiO_3)_2$. One of the minerals included in the term jade, is a tough compact translucent material of dark to pale green color found in Burma.

WOLLASTONITE.

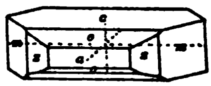
COMPOSITION. — $CaSiO_3$.

GENERAL DESCRIPTION. — Cleavable to fibrous, white or gray masses. Also in monoclinic crystals, near pyroxene in angle. Sometimes compact. Usually intermixed with calcite.

CRYSTALLIZATION. — Monoclinic. Axes $\breve{a} : \bar{b} : c = 1.053 : 1 : 0.967$; $\beta = 84° 30'$.

Common forms: unit prism m, unit dome o, pinacoids a and c and prism $z = (\breve{a} : \frac{3}{2}\bar{b} : \infty c)$; $\{320\}$. Supplement angles are: $mm = 92° 42'$; $zz = 69° 54'$; $co = 40° 3'$. Optically —. Axial plane b.

FIG. 522.



Harrisville, N. Y.

Physical Characters. H., 4.5 to 5. Sp. gr., 2.8 to 2.9.

LUSTRE, vitreous to silky. TRANSLUCENT.

STREAK, white. TENACITY, brittle.

COLOR, white, gray, or light tints of yellow, red, brown.

CLEAVAGE.—O and $i-\bar{i}$ at angle of 84° 30′.

BEFORE BLOWPIPE, ETC.—Fuses with difficulty, coloring the flame red. Soluble in hydrochloric acid, generally effervescing and always gelatinizing.

SIMILAR SPECIES.—Differs from pectolite and natrolite in red flame, difficulty of fusion, and absence of water. Tremolite does not gelatinize.

REMARKS.—Occurs in granular limestone, granite, basalt, lava, etc., with pyroxene, calcite, garnet, etc. By the action of carbonated or sulphurated waters it changes to calcite or gypsum.

PECTOLITE.

COMPOSITION. — $HNaCa_2(SiO_3)_3$.

GENERAL DESCRIPTION. — White or gray radiating needles and fibers of all lengths up to one yard. Also in tough compact masses and rarely in monoclinic crystals.

PHYSICAL CHARACTERS. — Translucent to opaque. Lustre, vitreous or silky. Color, white or gray. Streak, white. H., 5. Sp. gr., 2.68 to 2.78. Brittle.

BEFORE BLOWPIPE, ETC. — Fuses easily to a white enamel. Yields water in closed tube. Gelatinizes with hydrochloric acid.

REMARKS. — Occurs with zeolites, prehnite, etc., in cavities and seams of basic eruptive rocks.

RHODONITE.

COMPOSITION. — $MnSiO_3$, with replacement by Fe, Zn or Ca.

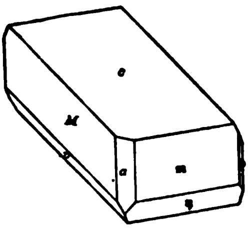
GENERAL DESCRIPTION. — Brownish red to bright red, fine

FIG. 523.

Pectolite, West Paterson, N. J. N. Y. State Museum.

grained or cleavable masses and disseminated grains, often coated with a black oxide. Sometimes in triclinic crystals either tabular parallel to c or like the forms of pyroxene.

FIG. 524.



Franklin Furnace.

CRYSTALLIZATION.—Fig. 524 shows three pinacoids a, b and c, the hemi-unit prisms m and M, and two quarter pyramids v, and $,v$ of $\bar{a} : b : 2c$. The supplement angles are $mM = 92° 28'$; $cm = 68° 45'$; $cM = 86° 23'$.

Physical Characters. H., 5.5 to 6.5. Sp. Gr., 3.4 to 3.68.

LUSTRE, vitreous. TRANSPARENT to opaque.

STREAK, white. TENACITY, brittle.

COLOR, brownish-red to flesh-red, bright-red, greenish, yellowish.

CLEAVAGE, prismatic, angle 87° 38′ and basal.

BEFORE BLOWPIPE, ETC.—Blackens and fuses easily with slight intumescence. With fluxes reacts for manganese and zinc. In powder is partially dissolved by hydrochloric acid, leaving a white residue. If altered may effervesce slightly during solution.

SIMILAR SPECIES.—Rhodochrosite is infusible, dissolves completely with effervescence in warm acids. Red feldspars are less fusible, and do not give manganese reactions.

REMARKS.—Occurs with iron-ore, franklinite, tetrahedrite, etc., and is altered by light, air, and carbonated waters to the oxides and the carbonates.

AMPHIBOLE. — Hornblende.

COMPOSITION. — $RSiO_3$, R being more than one of the elements, Ca, Mg, Fe, Al, Na and K.

GENERAL DESCRIPTION. — Monoclinic crystals either long with acute rhombic section or shorter with six-sided cross section. Often with ends like flat rhombohedron. Also columnar, fibrous and granular masses, rarely lamellar, often radiated. Colors : white, or shades of green, brown and black.

FIG. 525.

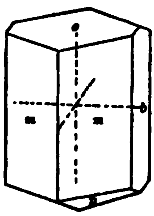
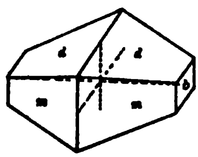
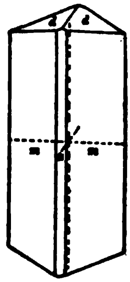


FIG. 526.



Russell, N. Y.

FIG. 527.



CRYSTALLIZATION. — Monoclinic. Axes $\grave{a} : \bar{b} : c = 0.551 : 1 : 0.294$; $\beta = 73° \ 58'$.

Common forms : unit prism *m*, pinacoids *b*, *c* and sometimes *a*, unit clino-dome *d* and unit pyramid *p*. Supplement angles are : $mm = 55° \ 49'$; $cm = 75° \ 52'$; $dd = 31° \ 32'$; $pp = 31° \ 41'$. Twinning as in pyroxene.

Optically +. Axial plane *b*. Strong double refraction. Often strongly pleochroic.

Physical Characters. H., 5 to 6. Sp. gr., 2.9 to 3.4.

LUSTRE, vitreous to silky. TRANSPARENT to opaque.
STREAK, white or greenish. TENACITY, brittle to tough.
COLOR, white, gray, green, black, brown, yellow and red.
CLEAVAGE, prismatic, angle of 124° 11'.

BEFORE BLOWPIPE, ETC.—Varies. Usually fuses easily to a colored glass, which may be magnetic. Not affected by acids.

VARIETIES:

Tremolite.—$CaMg_3(SiO_3)_4$, white to gray in color.

Actinolite.—$Ca(Mg.Fe)_3(SiO_3)_4$, bright green or grayish-green.

Hornblende and Edenite.—Aluminous varieties, black or green in color, with lustre something like horn.

All of these occur in crystals and columnar to fibrous.

Nephrite or Jade is compact and extremely tough, microscopically fibrous, may have composition of tremolite or actinolite.

Asbestus is in fine, easily separable fibres, white, gray, or greenish.

SIMILAR SPECIES.—Differs from tourmaline in cleavage, crystal line form and tendency to separate into fibres. The differences between it and pyroxene are:

Amphibole, prism angle and cleavage 124°; tough, often fibrous, rarely lamellar, often blade-like or pseudo-hexagonal crystals. Pyroxene, prism and cleavage angle 87°; brittle, rarely fibrous, often lamellar crystals, square or octagonal.

REMARKS.—Occurs with pyroxene, serpentine, talc, magnetite, quartz, the feldspars, etc, and forms by alteration, epidote, serpentine, talc, chlorite, iron-ores, etc.

Much of the material passing under the name of asbestus is fibrous serpentine. The best of the pure material is imported from Germany and Italy. Producing mines in the United States are located in California, Wyoming and Oregon. North Carolina, Georgia, Pennsylvania and other States have large deposits, but the quality and mode of occurrence do not allow it to be profitably mined at present. For most purposes the fibrous serpentine of Canada is superior to any American asbestus.

USES.—Asbestos is made into cloth and boards, which are incombustible and are good non-conductors of heat. It is used for roofing, coverings for steam pipes, piston packing, theatre curtains, firemen's suits, fire-proof paints and cements, and for lining safes. It is made into yarns, ropes and paper for fire-proof purposes. Asbestos of long fine fiber is used in the laboratory as a filtering medium.

Nephrite or jade has had many uses in prehistoric and more recent times. It is the toughest of all known stones and in the stone age was used for weapons and tools. In China and India and in ancient Mexico it was carved into ornaments, symbols of authority and sacrificial vessels, etc. It was supposed to be a cure for kidney diseases, and both its names are derived from words meaning "kidneys."

Glaucophane.—A sodium amphibole, $NaAl(SiO_3)_2.FeMgSiO_3$, blue in color and occurring in indistinct prisms or in columnar and fibrous masses especially in metamor-

phic schists. Crystals show distinctly different colors when viewed by transmitted light through different faces.

Uralite. — An amphibole pseudomorphic after pyroxene, having the crystal form of pyroxene and cleavage of amphibole.

Crocidolite. — A blue to green fibrous amphibole. An altered South African form of the compact mineral which has a peculiar changeable lustre is often used as a semi-precious stone gem under the name of "tiger's eye."

BERYL. — Emerald, Aquamarine.

COMPOSITION. — $Be_3Al_2(SiO_3)_6$.

GENERAL DESCRIPTION. — Hexagonal prisms, from mere threads to several feet in length. Usually some shade of green. Sometimes in large columnar or granular masses. Harder than quartz.

FIG. 528.

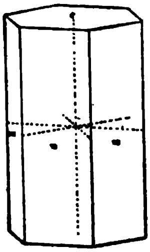


FIG. 529.

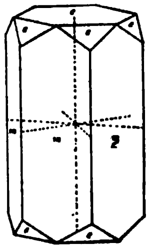
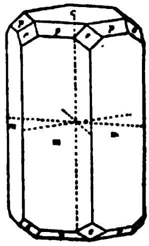


FIG. 530.



CRYSTALLIZATION. — Hexagonal. Axis $\dot{c} = 0.499$. Usually prism *m* with base *c*, sometimes with unit pyramid *p* or second order form $e = (2a : 2a : a : 2c)$; $\{11\bar{2}1\}$.. Supplement angles $cp = 29° 56'$; $ce = 44° 56'$.

Optically —. Low refraction and very low double refraction ($\alpha = 1.5659$; $\gamma = 1.5703$ for yellow light).

Physical Characters. H., 7.5 to 8. Sp. gr., 2.63 to 2.8.

LUSTRE, vitreous. TRANSPARENT to nearly opaque.

STREAK, white. TENACITY, brittle.

COLOR, emerald to pale-green, blue, yellow, white, red, colorless.

CLEAVAGE, imperfect basal and prismatic.

BEFORE BLOWPIPE, ETC.—Fuses on thin edges, often becoming white and translucent. Slowly dissolved in salt of phosphorus to an opalescent bead. Insoluble in acids.

VARIETIES.

Emerald.—Bright emerald green, from the presence of a little chromium.

Aquamarine.—Sky-blue to greenish-blue.
Goshenite.—Colorless.

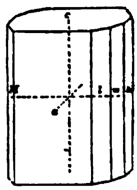
SIMILAR SPECIES.—Harder than apatite, quartz or tourmaline. Differs in terminal planes from quartz. Lacks distinct cleavage of topaz.

REMARKS.—Occurs in granite, mica-schist, clay-slate, etc., frequently penetrating the other minerals, showing that it was formed before them. It is associated with quartz, micas, feldspars, garnet, corundum, zircon, etc. By alteration it forms kaolinite, muscovite, etc. Beryls are especially abundant at Ackworth and Grafton, N. H.; Royalston, Mass.; Paris and Stoneham, Me.; Alexander County, N. C.; the Black Hills of South Dakota, and Litchfield, Conn. Those at Ackworth and Grafton are sometimes of immense size. One crystal, near the railroad station of Grafton Centre, measures 3 feet 4 inches by 4 feet 3 inches on horizontal section, and is exposed for over 5 feet. Good emeralds have been obtained in this country from Alexander County, S. C., and especially from Stony Point. Aquamarines and other gem specimens have been obtained at Paris and Stoneham, Me.; Mount Antero, Colo., and several places in North Carolina. Emeralds of finest quality are obtained near Muso, United States of Colombia, also from India, Brazil, Siberia and Australia.

USES.—Emerald and aquamarine are cut as gems.

CYANITE. — Kyanite.

FIG. 531.



COMPOSITION. — $(AlO)_2SiO_3$, probably a basic metasilicate.*

GENERAL DESCRIPTION. — Found in long blade-like triclinic crystals, rarely with terminal planes. The color is a blue, deeper along the center of the blades, and at times passes into green or white.

Physical Characters. H., 5 to 7. Sp. gr., 3.56 to 3.67.

LUSTRE, vitreous. TRANSLUCENT to transparent.
STREAK, white. TENACITY, brittle.
COLOR, blue, white, gray, green to nearly black.
CLEAVAGE, parallel to the three pinacoids.

BEFORE BLOWPIPE, ETC.—Infusible, with cobalt solution becomes blue. Insoluble in acids.

REMARKS. — Occurs chiefly in gneiss and mica schist, and appears to have been formed below 1300°, as at this temperature it is changed into fibrolite. It is associated with pyrophyllite, andalusite, corundum, etc., and is found throughout the corundum regions of Massachusetts, Pennsylvania, North Carolina, and Georgia.

* Dana places cyanite with the orthosilicates for convenience.

FIG. 532.

Cyanite, Pizzo Forno, St. Gothard, Switzerland. Foote Mineral Co.

IOLITE.—Dichroite, Cordierite.

COMPOSITION.—$Mg_3(Al.Fe)_6(SiO_4)_4(SiO_3)_4$.

GENERAL DESCRIPTION.—Short, six- or twelve-sided orthorhombic prisms and massive, glassy, quartz-like material. Usually blue in color. The color is often deep blue in one direction and gray or yellow in a direction at right angles with the first.

PHYSICAL CHARACTERS.—Transparent or translucent. Lustre, vitreous. Color, light to smoky blue, gray, violet or yellow. Dichroic. Streak, white. H., 7 to 7.5. Sp. gr., 2.6 to 2.66. Brittle. Cleaves parallel to brachy-pinacoid.

BEFORE BLOWPIPE, ETC.—Fuses with difficulty, becoming opaque. With cobalt solution becomes blue-gray. Partially soluble in acids.

REMARKS.—Occurs in gneiss and sometimes in granite, rarely in volcanic rocks, and is formed by contact with igneous matter. It is easily altered to a soft lamellar or fibrous material of green or yellow color, and is rarely found entirely unaltered.

ORTHOSILICATES.

The ORTHOSILICATES are derivatives of H_4SiO_4, as Zircon, $ZrSiO_4$; Phenacite, Gl_2SiO_4. Isomorphic mixtures are well represented by Biotite, $(H.K)_2(Mg.Fe)Al_2(SiO_4)_3$; acid salts by Prehnite, $H_2Ca_2Al_2(SiO_4)_3$, and basic salts by Sillimanite, $Al(AlO)SiO_4$. Haüynite is an example of a crystalline mixture of an orthosilicate and a sulphate. As a rule, the orthosilicates are less stable than the metasilicates.

The orthosilicates here described in detail are:

Nephelite	$7NaAlSiO_4 + NaAl(SiO_3)_2$	Hexagonal
Lazurite	Complex	Isometric
Garnet	$R_3''R_2'''(SiO_4)_3$	Isometric
Chrysolite	$(Mg.Fe)SiO_4$	Orthorhombic
Phenacite	Be_2SiO_4	Rhombohedral
Wernerite	Complex	Tetragonal
Vesuvianite	$Ca_6Al(OH.F)Al_2(SiO_4)_5$	Tetragonal
Zircon	$ZrSiO_4$	Tetragonal
Topaz	$Al(Al(O.F_2))SiO_4$	Orthorhombic
Andalusite	$Al(AlO)SiO_4$	Orthorhombic
Sillimanite	$Al(AlO)SiO_4$	Orthorhombic
Datolite	$Ca(B.OH\ SiO_4$	Monoclinic
Zoisite	$Ca_2Al_2(Al.OH)(SiO_4)_3$	Orthorhombic
Epidote	$Ca_2Al_2(Al.OH)(SiO_4)_3$	Monoclinic
Axinite	Complex	Triclinic
Prehnite	$H_2Ca_2Al_2(SiO_4)_3$	Orthorhombic

BIOTITE, PHLOGOPITE and MUSCOVITE, although derivatives of orthosilicic acid, are, according to the system of Dana, classified as hydrous silicates, while the probable orthosilicates, CHONDRODITE and STAUROLITE are classed as subsilicates.

NEPHELITE.—Elæolite.

COMPOSITION.—$7NaAlSiO_4 + NaAl(SiO_3)_2$. With partial replacement of Na by K or Ca.

GENERAL DESCRIPTION.—Small, glassy, white or colorless grains or hexagonal prisms with nearly flat ends, in lavas and eruptive rocks, or translucent reddish-brown or greenish masses and coarse crystals, with peculiar greasy lustre.

Physical Characters. H., 5.5 to 6. Sp. gr., 2.55 to 2.65.

LUSTRE, vitreous or greasy. TRANSPARENT to opaque.
STREAK, white. TENACITY, brittle.
COLOR, white, colorless, reddish, brownish, greenish or gray.
CLEAVAGE, prismatic and basal.

BEFORE BLOWPIPE, ETC.—Fuses to a colorless glass. When heated with cobalt solution, becomes blue. Soluble in hydrochloric acid, with residue of gelatinous silica.

VARIETIES.—The usually massive varieties, with greasy lustre, are called elæolite.

REMARKS.—Nephelite occurs in eruptive rocks and lavas. Elæolite occurs in granular, crystalline rocks such as syenite. Nephelite alters easily and is the source of many of the zeolites. Austin, Texas; Litchfield, Me., and the Ozark Mountains, Arkansas, are important localities of elæolite. Nephelite is abundant in the lavas of Vesuvius.

Cancrinite. — $H_6Na_6Ca(Na_2CO_3)_2Al_8(SiO_4)_9$ is a yellow to white (rarely blue) massive mineral usually associated with elæolite and blue sodalite. Rarely in hexagonal prisms. Optically —. It is found at Litchfield and Gardiner, Me.; Miask, Urals; Brevik, Norway and other localities.

Sodalite. — $Na_4(AlCl)Al_2(SiO_4)_3$ is found in bright blue to gray masses and embedded grains. Concentric nodules resembling chalcedony and rarely dodecahedral crystals sometimes of a pale pink color. It occurs at Litchfield, Me., various localities in Montana, Quebec, and Ontario; also in Vesuvius lavas, at Kaiserstuhl, Baden; and Miask, Urals.

Haüynite. — $2(Na_2Ca)Al_2(SiO_4)_2.(Na_2.Ca)SO_4$ possibly, but very complex and with varying proportions of Na and Ca. Occurs as glassy blue to green imbedded grains, or rounded isometric crystals in igneous rock.

Noselite. — Like haüynite but containing little or no lime.

LAPIS LAZULI or LAZURITE.—Native Ultramarine.

COMPOSITION.—An orthosilicate of sodium and aluminium, with a sulphate and a polysulphide of sodium.

GENERAL DESCRIPTION.—Deep-blue masses intimately mixed with other minerals. Rarely in isometric forms.

PHYSICAL CHARACTERS.—Translucent. Lustre, vitreous. Color, deep-blue, violet and greenish blue. Streak, white. H., 5 to 5.5. Sp. gr., 2.38 to 2.45. Brittle.

BEFORE BLOWPIPE, ETC.—Fuses easily to a white glass, with intumescence. In closed tube, glows with a green light and yields water. Soluble in hydrochloric acid with evolution of hydrogen sulphide and residue of gelatinous silica.

USES.—It is employed in inlaid work, and before the invention of artificial ultramarine it was very valuable as a durable, deep blue, color for oil paintings.

GARNET.

COMPOSITION.—$R''_3R'''_2(SiO_4)_3$. R'' is Ca, Mg, Fe or Mn. R''' is Al, Fe''' or Cr, rarely Ti.

GENERAL DESCRIPTION.—Imbedded isometric crystals, either complete or in druses and granular, lamellar and compact masses. Usually of some brown, red or black color, but occurring of all colors except blue, and harder than quartz. Also found in alluvial material as rounded grains.

FIG. 533.

Trapezohedral Garnet, Russell, Mass. N. Y. State Museum.

CRYSTALLIZATION. — Isometric. Usually a combination of the dodecahedron d and the tetragonal trisoctahedron, $n = (a : 2a : 2a)$;

FIG. 534.

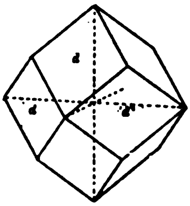


FIG. 535.

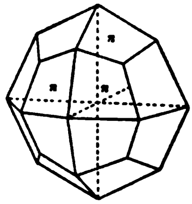
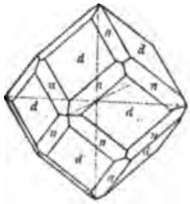


FIG. 536.



{211}, Fig. 536, or these as simple forms, Figs. 534, 535, or more rarely with the hexoctahedron, $s = (a : \frac{3}{2}a : 3a)$; {321}, Fig. 164. Index of refraction for red light 1.7645 to 1.7716.

Physical Characters. H., 6.5 to 7.5. Sp. gr.,* 3.15 to 4.38.

LUSTRE, vitreous or resinous. TRANSPARENT to opaque.

STREAK, white. TENACITY, brittle to tough.

COLOR, brown, black, violet, yellow, red, white, green.

CLEAVAGE, dodecahedral, imperfect.

BEFORE BLOWPIPE, ETC.—Fuses rather easily to light brown glass, except in case of infusible chromium and yttrium varieties. Insoluble before fusion, but after fusion will usually gelatinize with hydrochloric acid. Bead reactions vary with composition.

VARIETIES.

Grossularite.—$Ca_3Al_2(SiO_4)_3$. White, pale yellow, pale-green, brown-red rose-red.

Pyrope.—$Mg_3Al_2(SiO_4)_3$ Deep-red to nearly black, often transparent.

Almandite.—$Fe_3Al_2(SiO_4)_3$. Fine deep-red to black. Includes part of precious and of common garnet.

Spessartite.—$Mn_3Al_2(SiO_4)_3$. Brownish-red to purplish hyacinth red.

Andradite.—$Ca_3Fe_2(SiO_4)_3$. Yellow, green, red, brown, black. Includes many of the common garnets.

Uvarovite.—$Ca_3Cr_2(SiO_4)_3$. Emerald green, small crystals.

REMARKS.—Garnet is common in schists, gneiss, etc., and also occurs in granites, limestone, serpentine, and even in volcanic rocks. By oxidation of their ferrous iron and by the action of carbonated waters, garnets are altered, forming calcite, iron ores, soapstone, serpentine, gypsum, etc. The common garnet is a very common mineral in many localities throughout the United States. Precious garnets are found on the Navajo Reservation, New Mexico; in Southern Colorado, Arizona, Utah, Elliot

County, Ky.; Amelia County, Va.; Oxford County, Me.; and in North Carolina, Georgia, Montana, Idaho and Alaska. In Lewis and Warren Counties, N. Y.; Raburn County, Ga., and Burke County, N. C., garnets are so plentiful that they are mined for use as an abrasive.

USES.—Thousands of tons are used as an abrasive material intermediate in hardness between quartz and corundum. A marble containing large pink garnets is quarried at Morelos, Mexico, as an ornamental stone. Transparent red garnets are sometimes highly valued as gems, and the green variety is also sometimes cut.

CHRYSOLITE.—Olivine, Peridot.

COMPOSITION.—$(Mg.Fe)_2SiO_4$,

GENERAL DESCRIPTION.—Transparent to translucent, yellowish-green granular masses, or disseminated glassy grains, or olive-green sand. When containing much iron, the color may be reddish-brown, or even, by alteration, opaque-brown or opaque-green. Rarely in orthorhombic crystals.

CRYSTALLIZATION.—Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c} = 0.4657 : 1 : 0.5865$. Fig. 537 shows the pinacoids *a*, *b* and *c*, the unit forms of pyramid, prism, macro and brachy dome *m*, *p*, *o* and *d*, the macro prism $l = (\breve{a} : 2\bar{b} : \infty c)$; $\{210\}$ and macro pyramid $q = (\breve{a} : 2\bar{b} : c)$; $\{212\}$.

FIG. 537.

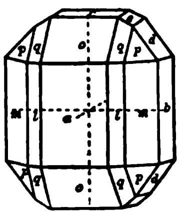


FIG. 538.

Supplement angles are $mm = 49° 57'$; $pp = 40° 5'$; $co = 51° 33'$; $cd = 49° 33'$.

Optically +. Axial plane *c*. Acute bisectrix normal to *a*. Strong refraction and double refraction ($\beta = 1.678$ and $2V = 87° 46'$, for yellow light).

In thin rock sections, Fig. 539, the outline, the distinct cleavage cracks and the frequent partial alteration to serpentine assist in its recognition.

Physical Characters, H., 6.5 to 7. Sp. gr., 3.27 to 3.57.
LUSTRE, vitreous. TRANSPARENT to translucent.
STREAK, white or yellowish. TENACITY, brittle.
COLOR, yellowish-green to brownish-red.

BEFORE BLOWPIPE, ETC.—Loses color, whitens, but is infusible unless proportion of iron is large, when it fuses to a magnetic globule. Soluble in hydrochloric acid with gelatinization of silica.

SIMILAR SPECIES.—Differs by gelatinization from green granular pyroxene. Is harder than apatite and less fusible than tourmaline.

REMARKS.—Of igneous origin, occurring in basalts, traps and crystalline schists, associated with such minerals as pyroxene, enstatite, amphibole, labradorite, chromite, etc. By alteration of its ferrous iron and by hydration forms limonite and serpentine, and the excess of magnesia usually forms magnesite. Further change may alter the serpentine to magnesite, leaving quartz or opal. Found at Thetford, Vt., Webster, N. C., Waterville, N. H., also in Virginia, Pennsylvania, New Mexico, Oregon, etc. Small gems are found in the garnet and sapphire regions of New Mexico, Arizona, Colorado, and Montana.

USES.—Transparent varieties are sometimes cut as gems.

HYALOSIDERITE. — A highly ferruginous variety of chrysolite, containing sometimes as high as thirty per cent. of ferrous oxide.

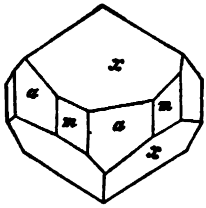
FAYALITE. — A chrysolite with nearly all of the Mg replaced by Fe so that the composition is that of a simple iron orthosilicate. H., 6.5. Sp. gr., 4.32. Fuses to a magnetic globule.

PHENACITE.

COMPOSITION. — Be_2SiO_4 (BeO 45.55, SiO_2 54.45 per cent.).

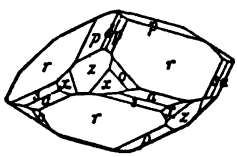
GENERAL DESCRIPTION. — Colorless, transparent, rhombohedral crystals, usually small, frequently lens-shaped. Sometimes yellowish and sometimes in prismatic forms. Harder than quartz.

FIG. 539.



Mt. Antero, Col.

FIG. 540.



Florissant, Col.

CRYSTALLIZATION. — Hexagonal. Class of third order rhombohedron, p. 48. Axis $\dot{c} = 0.661$. Supplement angles $xx = 75° 57'$; $rr = 63° 24'$. Optically +.

PHYSICAL CHARACTERS. — Transparent to nearly opaque. Lustre, vitreous. Color, colorless, yellow, brown. Streak, white. H. 7.5 to 8. Sp. gr. 2.97 to 3. Brittle. Cleavage, prismatic.

BEFORE BLOWPIPE, ETC. — Infusible and unaffected by acids. Made dull blue by cobalt solution.

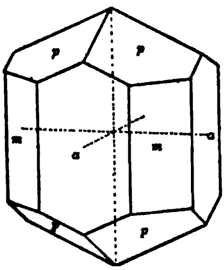
REMARKS. — Occurs with amazon stone, beryl, quartz, topaz, emerald, etc., and is sometimes used as an imitation gem.

WERNERITE.—Scapolite.

COMPOSITION. — A silicate of calcium, and aluminum, of complex composition. It contains also soda and chlorine.

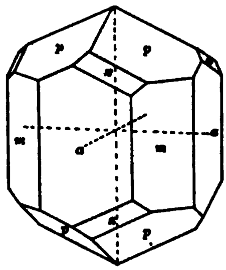
GENERAL DESCRIPTION. — Coarse, thick, tetragonal, "club-shaped," crystals, usually quite large and dull and of some gray, green, or white color. Cleavage surfaces have a characteristic fibrous appearance. Also in columnar and granular masses.

FIG. 541.



Usual form.

FIG. 542.



Meionite of Vesuvius.

CRYSTALLIZATION. — Tetragonal. Class of third order pyramid, p. 41. Axis $\dot{c} = 0.438$. Usually prisms of first order *m*, and second order *a*, and unit pyramid *p*. Supplement angle $pp = 43° 45'$. Optically —, with weak refraction and double refraction.

Physical Characters. H., 5 to 6. Sp. gr., 2.66 to 2.73.

LUSTRE, vitreous to dull. OPAQUE to translucent.

STREAK, white. TENACITY, brittle.

COLOR, gray, green, white, bluish, reddish.

CLEAVAGE., parallel to both prisms.

BEFORE BLOWPIPE, ETC.—Fuses with intumescence to a white glass containing bubbles. Imperfectly soluble in hydrochloric acid.

REMARKS.—Wernerite has been formed by heat at or near fusion. It is most abundant in granular limestone near contact with granite or similar rock. It occurs with pyroxene, apatite, garnet, zircon, biotite, etc., and is changed to pinite, mica, talc, etc, by atmospheric influence. Especially abundant at Bolton, Mass. Other localities common in New England, New York, New Jersey and elsewhere.

VESUVIANITE.—Idocrase.

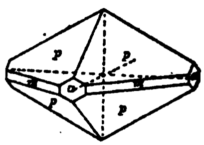
COMPOSITION. — $Ca_6[Al(OH, F)]Al_2(SiO_4)_5$ with replacement of Ca by Mn, and Al by Fe.

GENERAL DESCRIPTION. — Brown or green, square or octagonal prisms and less frequently in pyramidal forms. Also in columnar masses or granular or compact.

CRYSTALLIZATION. — Tetragonal. Axis $\dot{c} = 0.537$. Usually the unit prism *m* with base *c* and unit pyramid *p*. Prismatic faces often vertically striated. Supplement angles $pp = 50° 39'$; $cp = 37° 14'$.

Optically — (rarely +) with rather strong refraction but weak double refraction ($\alpha = 1.7226$; $\gamma = 1.7325$ for yellow light).

FIG. 543.



Monzoni, Tyrol.

FIG. 544.

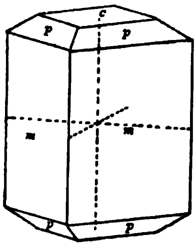
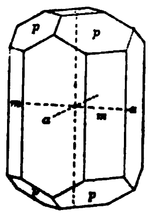


FIG. 545.



Physical Characters. H., 6.5. Sp. gr., 3 35 to 3.45.

LUSTRE, vitreous to resinous. TRANSLUCENT to opaque.
STREAK, white. TENACITY, brittle.
COLOR, brown or green, rarely yellow or blue Dichroic.
CLEAVAGE, indistinct, prismatic and basal.

BEFORE BLOWPIPE, ETC.—Fuses easily with intumescence to a green or brown glass. At high heat yields water in the closed tube. Very slightly affected by hydrochloric acid, but after ignition is dissolved leaving a gelatinous residue.

SIMILAR SPECIES.—The crystals and the columnar structure distinguish it from epidote, tourmaline, or garnet. The colors are not often like those of pyroxene.

REMARKS.—Vesuvianite occurs most frequently in metamorphic rocks, granular limestone, serpentine, chlorite, gneiss, etc., with garnet, muscovite, calcite, etc. It alters to talc, serpentine and calcite. Found at Parsonsfield and Rumford Falls, Me., Warren, N. H., Newton, N. J., Amity, N. Y. Also in California, Ontario and Quebec.

Melilite. — $Ca_{12}Al_4(SiO_4)_9$ with Na, Mg and Fe replacing Ca and Al, occurs in short prisms and in tabular orthorhombic crystals, especially in leucite and nephelite rocks and in melilite basalt.

ZIRCON.—Hyacinth.

COMPOSITION. — $ZrSiO_4$ (ZrO 67.2, SiO_2 32.8 per cent.).

GENERAL DESCRIPTION. — Small, sharp cut, square prisms and pyramids with adamantine lustre and brown or grayish color. Sometimes in large crystals and in irregular lumps and grains.

CRYSTALLIZATION. — Tetragonal. Axis $c = 0.640$. Common forms: unit prism *m*, unit pyramid *p*, second order prism *a*, and pyramids $u = (a : a : 3c)$; $\{331\}$ and $x = (a : 3a : 3c)$; $\{311\}$. Supplement angles $pp = 56° 41'$; $uu = 83° 9'$; $mu = 20° 12'$; $ax = 31° 53'$.

Optically + with strong refraction and double refraction ($\alpha = 1.9239$; $\gamma = 1.9628$ for yellow light).

FIG. 546.

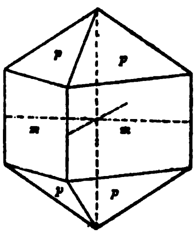


FIG. 547.

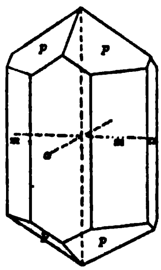


FIG. 548.

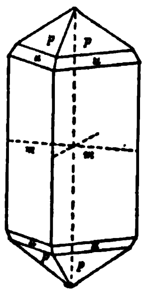
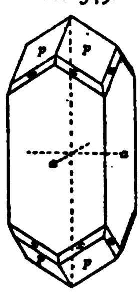


FIG. 549.



Physical Characteis. H., 7.5. Sp. gr., 4.68 to 4.70.

LUSTRE, adamantine. TRANSPARENT to opaque.

STREAK, white. TENACITY, brittle.

COLOR, brown, reddish, gray, colorless, green, yellow.

CLEAVAGES, imperfect, parallel to both pyramid and the prism.

BEFORE BLOWPIPE, ETC.—Infusible, losing color and sometimes becoming white. Insoluble in acids or in soda.

REMARKS.—Zircon is one of the first formed rock constituents, and is common as an enclosure in the others, especially the older eruptive rocks, granular limestone, schists. gneiss, syenite, granite, and iron ore. It is also found in alluvial depcsits.

Zircons have been mined at Green River, Henderson county, N. C., where they are especially abundant. Specimen localities are common throughout the United States and Canada.

USES.—As a source of zirconium oxide used in one variety of incandescent light. Transparent, red and brown varieties are cut under the name of hyacinth. Colorless or smoke varieties are called jargon, and are comparatively worthless.

TOPAZ.

COMPOSITION.—$Al_{12}Si_6O_{25}F_{10}$ or $Al(Al(O.F_2))SiO_4$.

GENERAL DESCRIPTION.—Hard, colorless or yellow transparent orthorhombic crystals with easy basal cleavage. Also massive in columnar aggregates, and as rolled fragments and crystals in alluvial deposits.

CRYSTALLIZATION.—Orthorhombic. $\breve{a} : \bar{b} : \dot{c} = 0.529 : 1 : 0.477$. Prisms often vertically striated. Crystals rarely doubly terminated. The predominating forms are the unit prism *m*, brachy

FIG. 550.

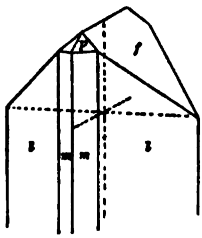


FIG. 551.

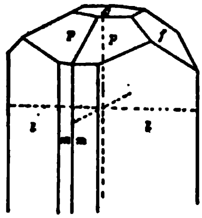
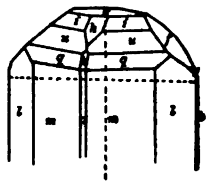


FIG. 552.



Omi, Japan.

prism $l = (2\breve{a} : \bar{b} : \infty c)$; $\{120\}$ (with predominance of *l* the section is often nearly square); base *c*, unit pyramid *p* and dome $f = (\infty \breve{a} : \bar{b} : 2c)$; $\{021\}$.

Supplement angles are: $mm = 55° 43'$; $ll = 93° 11'$; $pp = 38°$; ff (top) $= 87° 18'$.

Optically +. Axial plane *b*. Acute bisectrix normal to *c*. Refractive indices and axial angles vary considerably for different localities.

Physical Characters. H., 8. Sp. gr., 3.4 to 3.65.

LUSTRE, vitreous. TRANSPARENT to nearly opaque.

STREAK, white. TENACITY, brittle.

COLOR, colorless, yellow, pale-blue, green, white, pink.

CLEAVAGE, basal perfect.

BEFORE BLOWPIPE, ETC.—Infusible, but yellow varieties may become pink. With cobalt solution the powder becomes blue. Slowly dissolved in borax. If powdered and heated with previously fused salt of phosphorus in open tube the glass will be etched. Insoluble in acids.

REMARKS.—Probably always formed under the influence of heat. Occurs with minerals of similar origin in granite and gneiss, or less frequently in cavities in volcanic rock. Associates are the granite minerals and apatite, fluorite, cassiterite, beryl, zircon, etc.

Fine crystals of Topaz are found at Deseret, Utah, at Crystal Park, Cheyenne, and Devil's Head Mountain, Colo., Nathrop, Cal., Stoneham, Me., and Bald Mountain, N. H. Gems are also obtained from Siberia, Brazil, Japan, Australia, Mexico and other countries.

USES.—Transparent varieties are cut as gems.

ANDALUSITE.—Chiastolite.

COMPOSITION.—$Al(AlO)SiO_4$, (Al_2O_3 63.2, SiO_2 36.8 per cent.)

GENERAL DESCRIPTION.—Coarse, nearly square prisms of pearl gray or pale red color, or in very tough, columnar or granular masses. An impure soft variety (chiastolite) occurs in rounded prisms, any cross section of which shows a cross or checkered figure, due to the symmetrical deposition of the impurities, p. 133.

FIG. 553.

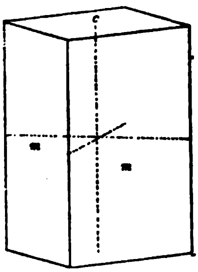
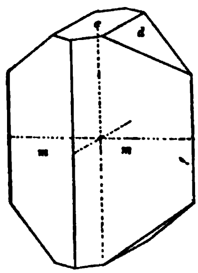


FIG. 554.



CRYSTALLIZATION.—Orthorhombic. Axes $\breve{a} : \bar{b} : c = 0.986 : 1 : 0.702$. Usually either the unit prism m, and base c, or these with the unit brachy dome d. Supplement angles are $mm = 89° 12'$; $dd = 70° 10'$.

Optically —. Axial plane the brachy-pinacoid. Acute bisectrix normal to c. Colored varieties strongly pleochroic.

Physical Characters. H., 7 to 7.5. Sp. gr., 3.16 to 3.20.

LUSTRE, vitreous. TRANSPARENT to opaque.

STREAK, white. TENACITY, brittle to tough.

COLOR, rose-red, flesh-red, violet, pale green, white, pearl-gray.

CLEAVAGE, prismatic, imperfect at angle of 90° 48′.

BEFORE BLOWPIPE, ETC.—Infusible. In powder becomes blue with cobalt solution. Insoluble in acids.

REMARKS.—It occurs in clay slates and in gneiss and schists with cyanite, fibrolite, quartz, etc. It alters rather readily to cyanite or kaolin. Found in many localities in the New England States, also in Pennsylvania and California. Foreign localities are numerous. Transparent crystals are found in Minas Geraes, Brazil.

SILLIMANITE or FIBROLITE.

COMPOSITION.—$Al(AlO)SiO_4$.

GENERAL DESCRIPTION.—Long, almost fibrous orthorhombic crystals, and fibrous or columnar masses of brown or gray color.

PHYSICAL CHARACTERS.—Transparent to translucent. Lustre, vitreous. Color, brown, gray, greenish. Streak, white. H., 6 to 7. Sp. gr., 3.23 to 3.24. Tough. Cleavage, parallel to brachy pinacoid.

BEFORE BLOWPIPE, ETC.—Infusible, becomes dark blue with cobalt solution. Insoluble in acids.

REMARKS.—Chiefly found in mica schist, gneiss, etc. Sometimes with andalusite.

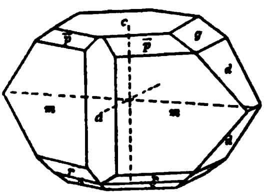
USES.—In the stone age it was used for tools, weapons, etc., being second only to jade in toughness.

DATOLITE.

COMPOSITION.—$Ca(B.OH)SiO_4$.

GENERAL DESCRIPTION.—Highly modified, glassy, monoclinic crystals often lining a cavity in a basic rock. Usually colorless, but also white or greenish. Also in compact, dull, white or pink masses, resembling unglazed porcelain.

FIG. 555.



Bergen Hill, N. J.

FIG. 556.

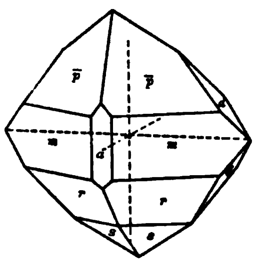
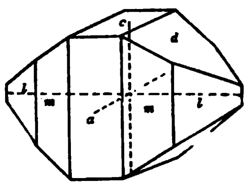


FIG. 557.



Lake Superior.

CRYSTALLIZATION. — Monoclinic. $\beta = 89° 51'$. Axes $\grave{a} : \bar{b} : \grave{c} = 0.634 : 1 : 1.266$. Prominent forms are the pinacoids a and c, the unit prism m, negative unit pyramid $\bar{p}$, unit clino-dome d, clino-prism $l = (2\grave{a} : \bar{b} : \infty c)$, $\{120\}$; and positive hemi-pyramid $r = (\grave{a} : \bar{b} : \frac{1}{2}c)$, $\{112\}$. Supplement angles are $mm = 64° 47'$; $ll = 76° 29'$; $\bar{p}\bar{p} = 59° 5'$; $dd = 103° 23'$.

Physical Characters. H., 5 to 5.5. Sp. gr., 2.9 to 3.

LUSTRE, vitreous. TRANSLUCENT to nearly opaque.

STREAK, white. TENACITY, brittle.

COLOR, colorless, white, greenish.

BEFORE BLOWPIPE, ETC.—In forceps or on charcoal fuses easily to a colorless glass, and if mixed with a flux of acid potassium sulphate and calcium fluoride and a little water it will color flame green. In closed tube yields water at a high heat. Soluble in hydrochloric acid, with gelatinization.

SIMILAR SPECIES. — Differs from the zeolites in crystalline form and flame and from colemanite by gelatinization.

REMARKS. — It is a secondary mineral found in basic eruptive rocks and sometimes in metallic veins. Often occurs with the zeolites, prehnite, calcite, etc. Found at Bergen Hill and Paterson, N. J.; at Hartford, Tariffville and Roaring Brook, Conn. Also in New York, Michigan, Massachusetts, California, etc.

ZOISITE. — Thulite.

COMPOSITION. — $Ca_2Al_2(Al.OH)(SiO_4)_3$.

GENERAL DESCRIPTION. — Gray or green and rose red (thulite) columnar and fibrous aggregates. More rarely, deeply striated orthorhombic prisms with indistinct terminations and perfect cleavage parallel to the brachy-pinacoid.

PHYSICAL CHARACTERS. — Transparent to opaque. Lustre, vitreous to pearly. Color, white, gray, brown, green, pink and red. Streak, white. H., 6-6.5. Sp. gr., 3.25-3.35. Optically +.

BEFORE BLOWPIPE, ETC. — Swells up and fuses easily to a glassy mass which does not readily assume globular form. Not affected by HCl before ignition, but after ignition it is decomposed with formation of jelly.

REMARKS. — Found at Ducktown, Tenn., Chesterfield, Mass., Uniontown, Pa., and many other localities.

EPIDOTE.

COMPOSITION. — $Ca_2Al_2(AlOH)(SiO_4)_3$ with some iron replacing aluminum.

GENERAL DESCRIPTION. — Coarse or fine granular masses of peculiar yellowish-green (pistache green) color, sometimes fibrous.

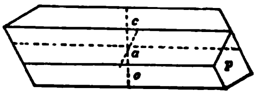
Also in monoclinic crystals and columnar groups, from yellow-green to blackish-green in color.

FIG. 558.

Epidote, Sulzbach, Tyrol. N. Y. State Museum.

CRYSTALLIZATION. — Monoclinic. $\beta = 64° \; 37'$. Axes $\grave{a} : \bar{b} : \grave{c} = 1.579 : 1 : 1.804$. Common forms : m = unit prism, a and c pinacoids, p unit pyramid and o unit dome. Supplement angles are $mm = 109° \; 56'$; $ca = 64° \; 37'$; $co = 63° \; 42'$. Crystals extended in the direction of the ortho-axis.

FIG. 559.



Optically —. Axial plane the clinopinacoid. Acute bisectrix nearly vertical. Refraction and double refraction both strong. Pleochroism strong. Sometimes shows colored absorption figure when held close to the eye.

Physical Characters. H., 6 to 7. Sp. gr., 3.25 to 3.5.

LUSTRE, vitreous. TRANSPARENT to opaque.

STREAK, white. TENACITY, brittle.

COLOR, yellowish-green to nearly black and nearly white, also red and gray. CLEAVAGE, basal, easy.

BEFORE BLOWPIPE, ETC.—Fuses easily with intumescence to a dark, usually slightly magnetic, globule. At high heat yields water. Slightly soluble in hydrochloric acid, but if previously ignited, it dissolves, leaving gelatinous silica.

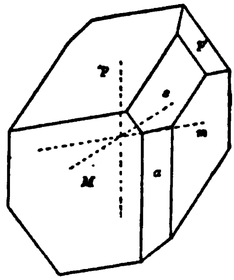
REMARKS.—Formed chiefly by alteration of the feldspars, hornblende or biotite, etc., and is common in many crystalline rocks, often accompanying beds of iron in these rocks. It is not readily altered. Common throughout New England and many of the western States.

Piedmontite. — A red manganiferous epidote. Crystals show different colors by transmitted light when viewed through different planes.

Allanite. — A silicate of the cerium and yttrium groups with lime and iron. Occurs in pitch black or brownish embedded veins and masses and flat tabular or prismatic monoclinic crystals.

AXINITE.

FIG. 560.



COMPOSITION. — An orthosilicate containing, especially, boron, aluminium, and calcium with some iron and manganese.

GENERAL DESCRIPTION. — Occurs in acute-edged triclinic crystals, see Fig. 560, usually of clove brown, bluish or yellow color. Also occurs lamellar or massive with bright glassy lustre.

PHYSICAL CHARACTERS. — Translucent to transparent. Lustre, highly vitreous. Color brown, bluish, yellow, gray and greenish. Streak, white. H., 6.5–7. Sp. gr., 3.25–3.27. Optically —.

BEFORE BLOWPIPE, ETC. — Fuses easily with bubbling to a dark greenish or black glassy globule. Reacts for boron. Gelatinizes with HCl after ignition.

REMARKS. — Fine crystals are obtained in Bourg d'Oisans, Dauphiné; and Mt. Skopi, Switzerland.

PREHNITE.

COMPOSITION. — $H_2Ca_2Al_2(SiO_4)_3$.

GENERAL DESCRIPTION. — A green to grayish-white vitreous mineral. Sheaf-like groups of tabular crystals, united by the basal planes. Sometimes barrel-shaped crystals and frequently reniform or botryoidal crusts, Fig. 270, with crystalline surface.

Physical Characters. H., 6 to 6.5. Sp. gr., 2.8 to 2.95.

LUSTRE, vitreous.	TRANSLUCENT.
STREAK, white.	TENACITY, brittle.
COLOR, light to dark green or grayish-white.	CLEAVAGE, basal.

BEFORE BLOWPIPE, ETC.—Easily fusible to a whitish glass containing bubbles. In closed tube yields a little water. Soluble in hydrochloric acid, and after *fusion* is soluble with a gelatinous residue.

SIMILAR SPECIES.—Resembles calamine or green smithsonite somewhat, but is more easily fused, and does not gelatinize unless previously ignited.

Remarks.—Occurs in granite gneiss, trap, syenite, etc., as a secondary mineral derived from their alteration, and associated with other secondary minerals as datolite or the zeolites. Bergen Hill and Paterson, N. J., have furnished a few gem stones. Other localities are Farmington, Conn., the Tamarack and Quincy copper mines, Mich., Perry, Me., and Westport, N. Y.

Uses.—To a limited extent has been cut as a gem.

BASIC OR SUBSILICATES.

Made a division by Dana because their constitution is not definitely settled, though probably each belongs to one of the preceding groups.

Here are described:

Chondrodite	$H_2Mg_{19}Si_8O_{34}F_4$	Monoclinic
Tourmaline	$R_{18}B_2(SiO_5)_4$	Hexagonal
Staurolite	$Fe(AlO)_4(Al.OH)(SiO)_4$	Orthorhombic

CHONDRODITE.

Composition.—$H_2Mg_{19}Si_8O_{34}F_4$, or $(Mg.Fe)_{13}(Mg.F)_4(MgOH)_2(SiO_4)_8$, with some iron replacing magnesium.

General Description.—The chemical compound occurs as three crystallographically distinct species, chondrodite, humite, clinohumite. Chondrodite proper consists of compact brown masses or disseminated grains and yellowish-brown to red, monoclinic, pseudo orthorhombic, crystals of great complexity.

Physical Characters.—Translucent. Lustre, vitreous. Color, brown, garnet-red, light to dark yellow. Streak, white. H, 6 to 6.5. Sp. gr., 3.1 to 3.2. Brittle.

Before Blowpipe, Etc.—Infusible, sometimes blackens and then turns white. Fused with powdered salt of phosphorus *glass* will yield fluorine. Soluble in hydrochloric acid with gelatinization.

Remarks.—Chiefly found in crystalline limestone or with other magnesium minerals. Alters to serpentine.

TOURMALINE.—Schorl.

Composition.—$R_{18}B_2(SiO_5)_4$. R chiefly Al, K, Mn, Ca, Mg, Li.

General Description.—Prismatic crystals, the cross sections of which frequently show very prominently a triangular prism. Color, usually some dark smoky or muddy tint of black, brown or blue, also bright green, red, and blue, or rarely colorless. Sometimes the centre and outer shell are different colors, as red and green. Sometimes the color is different at two opposite ends. Occurs also columnar in bunches or radiating aggregates and in compact masses.

Crystallization. — Hexagonal. Hemimorphic class, p. 46. Axis $c = 0.448$.

Prevailing forms: trigonal prism *m*, second order prism *a*, unit rhombohedron *p*, negative rhombohedron $f = (a : \infty a : a : 2c)$, $\{20\bar{2}1\}$. Supplement angles are: $pp = 46° 52'$; $ff = 77°$; $mp = 62° 40'$.

Optically —. Strongly dichroic, absorption very marked for rays vibrating parallel to the vertical axis. Double refraction rather strong.

FIG. 561.

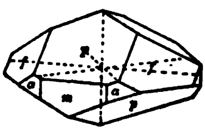


FIG. 562.

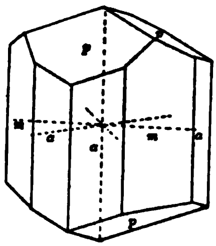
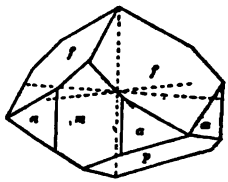


FIG. 563.



Physical Characters. H., 7 to 7.5. Sp. gr., 2.98 to 3.20.

LUSTRE, vitreous or resinous. TRANSPARENT to opaque.

STREAK, white. TENACITY, brittle.

COLOR, black, brown, green, blue, red, colorless.

CLEAVAGE, difficult, parallel to *R* and *i* – 2.

BEFORE BLOWPIPE, ETC.—Usually fuses, sometimes very easily. With a paste of $KHSO_4$,CaF_2 and water it yields a green flame. Insoluble in acids, but after strong ignition gelatinizes.

SIMILAR SPECIES.—Differs from hornblende in hardness, crystalline form and absence of prismatic cleavage. Differs from garnet or vesuvianite in form, difficult fusion, and green flame.

REMARKS.—Occurs in crystalline rocks: granite, gneiss, mica-schists, crystalline limestone, etc., with many associates. By alteration it forms cookeite, lepidolite, talc, and chlorite. Tourmalines of gem value have been obtained in some quantity from Paris, Auburn, and Hebron, Me., and from Riverside county, California.

USES.—Transparent, red, yellow, and green varieties are cut as gems. Thin plates are used to polarize light.

STAUROLITE.

COMPOSITION.—$Fe(AlO)_4(AlOH)(SiO_4)_2$, but varying. May contain Mg or Mn.

GENERAL DESCRIPTION.—Dark brown to nearly black orthorhombic prisms often twinned, or in threes, crossing at 90° and 120°. Surfaces bright if unaltered. Very hard.

FIG. 564.

Tourmaline in Lepidolite, San Diego Co., Cal. N. Y. State Museum.

CRYSTALLIZATION.—Othorhombic. Axes $\breve{a} : \bar{b} : \dot{c} = 0.473 : 1 : 0.683$. Usual forms: unit prism *m*, unit dome *o* and pinacoids *b* and *c*. Frequently in twins crossed nearly at right angles, Fig. 566, or nearly at 60°, Fig. 567.

Supplement angles are: $mm = 50° 40'$; $co = 55° 14'$. Optically +. Axial plane the macro-pinacoid. Acute bisectrix, normal to *c*.

FIG. 565

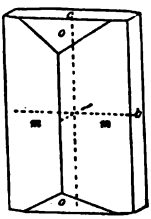


FIG. 566.

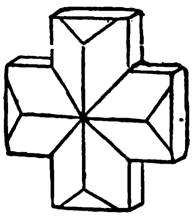
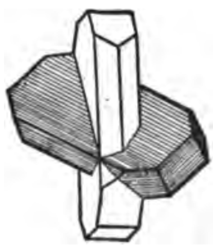


FIG. 567.



Physical Characters. H., 7 to 7.5. Sp. gr., 3.65 to 3.75.

LUSTRE, resinous or vitreous. TRANSLUCENT to opaque.

STREAK, white. TENACITY, brittle.

COLOR, dark brown, blackish-brown, gray when weathered.

CLEAVAGE, parallel to brachy pinacoid.

BEFORE BLOWPIPE, ETC.—Infusible, except when manganiferous. Partially soluble in sulphuric acid.

REMARKS.—Occurs chiefly in schistose rock with andalusite, garnet, tourmaline, cyanite, etc., but is not found in schists rich in amphibole. Abundant at Claremont, Grantham, and Lisbon, N. H., at Windham, Me., Chesterfield, Mass., Litchfield, Conn., and several other localities in New England. Also in New York, North Carolina, Georgia, and Pennsylvania.

HYDROUS SILICATES.

Compounds containing water of crystallization with certain closely related species in which the water plays the part of a base or is in doubt.

The minerals described here are:

	ZEOLITE DIVISION.	
Apophyllite	$H_{14}K_2Ca_8(SiO_3)_{16} + 9H_2O$	Tetragonal
Heulandite	$H_4CaAl_2(SiO_3)_6 + 3H_2O$	Monoclinic
Stilbite	$H_4(Na_2Ca)Al_2(SiO_3)_6 + 4H_2O$	Monoclinic
Chabazite	$(Ca.Na_2)Al_2(SiO_3)_4 + 6H_2O$	Hexagonal
Analcite	$NaAl(SiO_3)_2 + H_2O$	Tetragonal
Natrolite	$Na_2Al(AlO)(SiO_3)_3 + 2H_2O$	Orthorhombic
	MICA DIVISION.	
Muscovite	$H_2(K.Na)Al_3(SiO_4)_3$	Monoclinic
Biotite	$(H.K)_2(Mg.Fe)_2Al_2(SiO_4)_3$	Monoclinic
Phlogopite	$R_3Mg_3Al(SiO_4)_3$	Monoclinic
Chlorite	Silicate of H, Mg, Fe, Al	Monoclinic
	SERPENTINE AND TALC DIVISION.	
Serpentine	$H_4Mg_3Si_2O_9$	
Talc	$H_2Mg_3(SiO_3)_4$	Monoclinic
Sepiolite	$H_4Mg_2Si_3O_{10}$	
	KAOLIN DIVISION.	
Kaolinite	$H_4Al_2Si_2O_9$	Monoclinic
Pyrophyllite	$HAl(SiO_3)_2$	Monoclinic

ZEOLITES.

The zeolites are a group of silicates, all of which are of a secondary origin and are usually found in the seams or cavities of basic igneous rocks, such as basalt or diabase, and less frequently in granite or gneiss.

They are similar to the feldspars in constituents and combining ratios, and are chiefly formed from the feldspars and from nephelite, leucite, etc. Most of them fuse easily, with appearance of boiling, and all contain water of crystallization. The hardness varies from 3.5 to 5.5, and the specific gravity from 2.0 to 2.4.

APOPHYLLITE.

COMPOSITION.—$H_{14}K_2Ca_8(SiO_3)_{16} + 9H_2O$, with replacement by fluorine.

GENERAL DESCRIPTION.—Colorless and white or pink, square crystals. Sometimes flat, square plates or approximate cubes; at other times pointed and square to nearly cylindrical in section. Notably pearly on base or may show in vertical direction a peculiar —fish eye—internal opalescence. Found occasionally in lamellar masses.

CRYSTALLIZATION.—Tetragonal. Axis $c = 1.252$. Usually combinations of unit pyramid p, base c, and second order prism a. Supplement angle $pp = 76°$; $cp = 60° 32'$. Prism faces vertically striated.

FIG. 568.

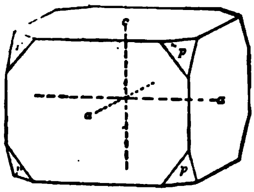


FIG. 569.

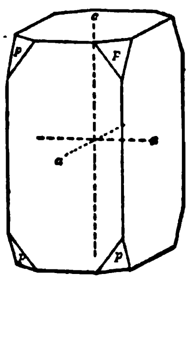
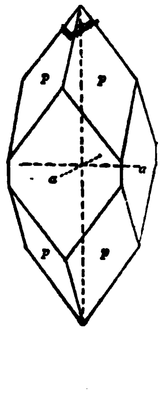


FIG. 570.



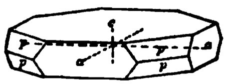


FIG. 571.

Physical Characters. H., 4.5 to 5. Sp. gr., 2.3 to 2.4.

LUSTRE, vitreous or pearly. TRANSPARENT to nearly opaque.
STREAK, white. TENACITY, brittle.
COLOR, colorless, white, pink or greenish. CLEAVAGE, basal.

BEFORE BLOWPIPE, ETC. — Exfoliates and fuses to a white enamel. In closed tube yields water. In hydrochloric acid forms flakes and lumps of jelly.

REMARKS.—Occurs in volcanic rocks and mineral veins with zeolites, datolite, pectolite, etc. It is a secondary mineral.

HEULANDITE.

COMPOSITION. — $H_4CaAl_2(SiO_3)_6 + 3H_2O$.

GENERAL DESCRIPTION. — Monoclinic crystals, with very bright, pearly, cleavage surfaces. The face parallel to the cleavage is also bright pearly, and is less symmetrical than the corresponding face of stilbite.

PHYSICAL CHARACTERS. — Transparent to translucent. Lustre, pearly and vitreous. Color, white, red, brown. H., 3.5–4. Sp. gr. 2.18–2.22. Brittle. Cleaves parallel to a pearly face.

BEFORE BLOWPIPE, ETC. — Exfoliates and fuses easily to a white enamel. In the closed tube yields water. Soluble in hydrochloric acid, with a residue of fine powder.

STILBITE. — Desmine.

COMPOSITION. — $H_4(Na_2.Ca)\ Al_2(SiO_3)_6 + 4H_2O$.

GENERAL DESCRIPTION.—Tabular crystals, of white, brown or red color, pearly in lustre on broad faces and frequently united by these faces in sheaf-like groups. Sometimes globular or radiated. Crystals are orthorhombic in appearance, but really complex monoclinic twins.

FIG. 572.

Cape Blomidon, N. S.

Physical Characters. H., 3.5 to 4. Sp. gr., 2.09 to 2.2.

LUSTRE, vitreous or pearly. TRANSLUCENT.

STREAK, white. TENACITY, brittle.

COLOR, yellow, brown, white, red.

CLEAVAGE, parallel to pearly face.

BEFORE BLOWPIPE, ETC.—Swells and exfoliates in fan shapes, and fuses easily to a white, opaque glass. Yields water in closed tube. Soluble in hydrochloric acid, with a pulverulent residue.

REMARKS.—Occurs with other zeolites.

CHABAZITE.

COMPOSITION. — $(Ca,\ Na_2)Al_2(SiO_3)_4 + 6H_2O$.

GENERAL DESCRIPTION. — Simple rhombohedral crystals, almost cubic, also in modified forms and twins. Faces striated parallel to edges. Color, white, pale-red and yellow.

Physical Characters. H., 4 to 5. Sp. gr., 2.08 to 2.16.

LUSTRE, vitreous.	TRANSLUCENT, transparent.
STREAK, white.	TENACITY, brittle.
COLOR, white, red, yellow.	CLEAVAGE, parallel to the unit rhombohedron.

CRYSTALLIZATION. — Hexagonal. Scalenohedral class, p. 42. Axis $c = 1.086$. Unit rhombohedron p and negative rhombohedra $e = (a : \infty a : a : \frac{1}{2}c)$; $\{10\bar{1}2\}$, and $f = (a : \infty a : a : 2c)$; $\{20\bar{2}1\}$ are most common. Supplement angles $pp = 85° \ 14'$; $ee = 54° \ 47'$.

Optically − usually, sometimes + ; interference figure confused.

FIG. 573.

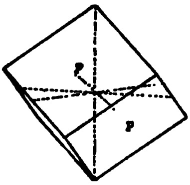


FIG. 574.

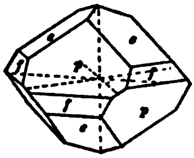
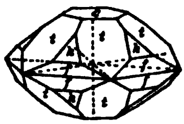


FIG. 575.



BEFORE BLOWPIPE, ETC. — Intumesces and fuses to a nearly white glass containing bubbles. Yields water in closed tube. Soluble in hydrochloric acid, leaving flakes and lumps of jelly.

REMARKS. — Occurs generally in basaltic rocks. Found in several localities in Nova Scotia. Also at Baltimore, Md.; Aussig, Bohemia; Faroer, Greenland; Richmond, Victoria.

ANALCITE.

COMPOSITION. — $NaAl(SiO_3)_2 + H_2O$.

GENERAL DESCRIPTION. — Small white or colorless trapezohe-

FIG. 576.

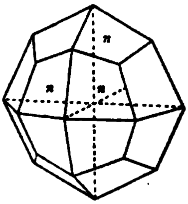


FIG. 577.

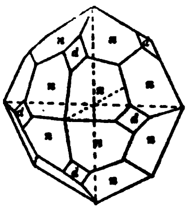
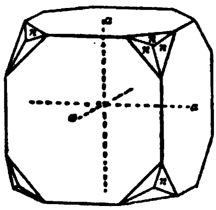


FIG. 578.



Island of Cyclops.

drons, Figs. 576, 577, or modified cubes, Fig. 578; rarely granular or compact with concentric structure.

CRYSTALLIZATION. — Isometric. The trapezohedron $n = (a : 2a$

: $2a$); {211}, is most frequent sometimes modified by the cube a or dodecahedron d, and in some crystals the cube predominates.

Physical Characters.—H., 5 to 5.5. Sp. gr., 2.2 to 2.29.

LUSTRE, vitreous. TRANSPARENT to opaque.
STREAK, white. TENACITY, brittle.
COLOR, white, colorless, greenish, red.

BEFORE BLOWPIPE, ETC.—Fuses easily and quietly to a clear, colorless glass. Yields water in closed tube. Gelatinizes with hydrochloric acid.

REM... —A secondary mineral, usually with other zeolites.

NATROLITE. — Needle Zeolite.

COMPOSITION. — $Na_2Al(AlO)(SiO_3)_3 + 2H_2O$.

GENERAL DESCRIPTION. — Colorless to white, slender, nearly square prisms, with very flat pyramids. Usually in radiating and interlacing clusters and bunches. Also fibrous granular and compact.

CRYSTALLIZATION. — Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c} = 0.979 : 1 : 0.354$. Angle of prism = 88° 46′.

Physical Characters. H., 5 to 5.5. Sp. gr., 2.2 to 2.25.

LUSTRE, vitreous. TRANSPARENT to opaque.
STREAK, white. TENACITY, brittle.
COLOR, colorless, white, yellow, red. CLEAVAGE, prismatic.

BEFORE BLOWPIPE, ETC.—Fuses very easily to a colorless glass. In closed tube, yields water. Soluble in hydrochloric acid, with gelatinization.

SIMILAR SPECIES.—Differs from pectolite in square cross-section and fusion to a clear, colorless glass.

REMARKS —Occurs with other zeolites and with prehnite, calcite and datolite.

Thomsonite. —$(Ca.Na_2)_2Al_4(SiO_4)_4 + 5H_2O$. Usually in radiating fibers or slender prismatic crystals or amygdaloidal with fibrous structure radiating from several centers and of different colors.

THE MICA DIVISION.

The micas are common constituents of granites, gneisses and schists, and are characterized principally by the very perfect basal cleavage into elastic flakes. They occur as monoclinic crystals with prism angles of closely 120°, which usually appear either

hexagonal or orthorhombic. Cleavages show the interference figure because the acute bisectrix is nearly normal to the base. In all the species a blow from a conical point upon a cleavage surface develops a so-called percussion figure, consisting of three cracks, one parallel to the plane of symmetry, the others at definite angles to this.

The angle between the optic axes and the relative position of the axial plane and the principal line of the percussion figure give convenient distinctions.

MUSCOVITE. — Potash Mica, White Mica, Isinglass.

COMPOSITION. — $H_2(K.Na)Al_3(SiO_4)_3$, with some replacement by Mg or Fe.

GENERAL DESCRIPTION. — Disseminated six-sided scales and rough crystals, which cleave with great ease into thin, elastic, transparent leaves. Also in masses of coarse or fine scales sometimes grouped in globular and plumose forms, Fig. 272. Usually transparent and pale gray in color, and with pearly lustre on the cleavage surfaces.

CRYSTALLIZATION. — Monoclinic. $\beta = 89° 54'$. Prism angle $= 59° 48'$. Crystals usually rhombic or hexagonal in section, with rough faces, and usually tapering. Sometimes very large, several feet across. Cleavage is approximately at right angles to the prism.

Optically —. Axial plane at 90° to *b* and near 90° to *c*; that is, at 90° to the principal line of the percussion figure. Axial angle variable but large, $2E$ 50° to 70°. Pleochroism feeble. Absorption in sections cut at 90° to the cleavage very strong.

Physical Characters. H., 2 to 2.5. Sp. gr., 2.76 to 3.

LUSTRE, vitreous, pearly on cleavage. TRANSPARENT in laminæ.
STREAK, white. TENACITY, elastic.
COLOR, gray, brown, green, yellow, violet, red, black.
CLEAVAGE, basal, eminent.

BEFORE BLOWPIPE, ETC.—Fuses only on thin edges to a yellowish glass. Insoluble in acids.

SIMILAR SPECIES.—Differs from talc or gypsum in being elastic. Is *usually* lighter colored than biotite.

REMARKS.—Muscovite is of both igneous and secondary origin. It occurs with quartz and feldspars, in granite, gneiss and mica schist and related rocks and more or less disseminated in other rocks, and it also is found formed from cyanite, topaz, feldspars, corundum, etc. The most productive mica mines of the United States are in Mitchell, Yancey, Jackson and Macon Counties, S. C., and Groton, N. H. Other large deposits exist at Grafton, N. H.; Las Vegas and Cribbensville, N. M., and Deadwood and the Black Hills, S. D., many of which are intermittently mined. Also in Nevada, California, Colorado and Pennsylvania in quantity and quality fit for use. Large quantities of mica are annually imported from India.

USES. — In sheets as transparent material in doors of furnaces, stoves, etc. As insulating material in electrical apparatus, especially on the armatures of dynamos. Ground as a coating for spangling wall papers and such fabrics as brocade; producing the frosted appearance of Christmas cards; as an absorbent of nitro-glycerine; as a non-conducting material for heat and electricity; for a lubricant and for a mica paint giving a spangled appearance to the coated object.

DAMOURITE. — An altered hydrous potassium mica in small scales or fibrous. Cleavage plates less elastic and of silky luster.

BIOTITE. — Black Mica, Magnesium Mica.

COMPOSITION. — An orthosilicate approximating $(H.K)_2(Mg.Fe)_2$-$Al_2(SiO_4)_3$.

GENERAL DESCRIPTION. — The most common of the micas. Accompanies muscovite in granitic rocks and schists, but is usually dark green to black in color and in comparatively small scales. Also as black, green and red crystals at Vesuvius. It cleaves into thin, elastic leaves.

Optically —. Axial plane usually parallel to *b*; that is *parallel* to the principal line of the percussion figure. Axial angle usually small, $2E$ varying 0 to 12°, rarely 50°. Pleochroism strong.

Physical Characters. H., 2.5 to 3. Sp. gr., 2.7 to 3.1.

LUSTRE, pearly, vitreous, submetallic. TRANSPARENT to opaque.
STREAK, white. TENACITY, tough and elastic.
COLOR, commonly black to green. CLEAVAGE, basal, eminent.

BEFORE BLOWPIPE, ETC.—Whitens and fuses on thin edges. Decomposed by boiling sulphuric acid, with separation of scales of silica.

REMARKS.—Occurrence and associates like muscovite, but is more common than muscovite in the eruptive rocks. It is found in most of the muscovite localities, and is a very common constituent of rocks and soils in the form of small scales. It alters more readily than muscovite to chlorite or to epidote, quartz and iron oxide.

PHLOGOPITE. — Amber Mica, Bronze Mica.

COMPOSITION. — $R_3Mg_3Al(SiO_4)_3$, where R = H,K,MgF.

GENERAL DESCRIPTION. — Large and small, brownish-red to nearly black crystals. Usually rough, tapering, six-sided prisms. Thin plates sometimes show a six-rayed star by transmitted light.

Optically —. Axial plane parallel to *b*, that is *parallel* to the principal line of the percussion figure. Axial angle small, but varying in the same specimen. Pleochroic in colored varieties.

Physical Characters. H., 2.5 to 3. Sp. gr., 2.78 to 2.85.

LUSTRE, pearly or submetallic. TRANSPARENT to translucent.
STREAK, white. TENACITY, tough and elastic.
COLOR, yellowish-brown, brownish-red, green, colorless.
CLEAVAGE, basal eminent.

BEFORE BLOWPIPE, ETC.—Whitens and fuses on thin edges. In closed tube yields water. Soluble in sulphuric acid with separation of scales of silica.

REMARKS.—Phlogopite is usually found in crystalline limestones or in serpentine. It occurs in enormous crystals in Ontario and Quebec, and in various localities through New York and New Jersey.

USES. — It is largely used in electrical work as an insulating material.

CHLORITE. — Prochorite, Clinochlore, Ripidolite.

COMPOSITION. — Silicates of iron, magnesia and alumina containing about 12 per cent. of water.

GENERAL DESCRIPTION. — Dark-green masses, composed of coarse to very fine scales. Also tabular and curiously twisted six-sided crystals, which easily cleave into thin plates which are soft and pliable but not elastic. Also frequently distributed as a pigment in other minerals.

Physical Characters. H., 1 to 2.5. Sp. gr., 2.65 to 2.96.

LUSTRE, feebly pearly. TRANSLUCENT to opaque.
STREAK, white or greenish. TENACITY, flexible, non-elastic.
COLOR, grass-green, blackish-green or red.
CLEAVAGE, basal perfect. FEEL, slightly soapy.

Before Blowpipe, Etc.—Whitens and then fuses, varying from easy fusion to black magnetic glass to difficult fusion to a yellow enamel. In closed tube yields water at a high heat. Soluble in sulphuric acid, only slightly in hydrochloric acid.

Remarks.—Formed by decomposition of mica and aluminous varieties of amphibole, garnet, pyroxene and feldspars, and occasionally found as an earthy substance in cavities of crystalline schists and serpentines.

Delessite, a dark-green massive mineral of scaly or short fibrous appearance. H., 2.5. Sp. gr., 2.9. It yields water in the closed tube and is decomposed by HCl with separation of silica. Found in cavities of amygdaloidal eruptive rocks.

SERPENTINE AND TALC DIVISION.

SERPENTINE.

Composition.—$H_4Mg_3Si_2O_9$, with replacement by Fe.

General Description.—Fine granular masses or microscopically fibrous. Also foliated and coarse or fine fibrous. Color, green, yellow or black, and usually of several tints dotted, striped and clouded. Very feeble, somewhat greasy lustre and greasy feel. Crystals unknown.

Physical Characters. H., 2.5 to 4., Sp. gr., 2.5 to 2.65.

Lustre, greasy, waxy or silky. Translucent to opaque.
Streak, white. Tenacity, brittle.
Color, green to yellow, brown, red, black, variegated.

Before Blowpipe, Etc.—Fuses on edges. In closed tube, yields water. In cobalt solution becomes pink. Soluble in hydrochloric acid, with a residue.

Remarks.—A secondary mineral formed from chrysolite, amphibole, pyroxene, enstatite, etc. It is associated with these and with magnetite, garnierite, chromite, dolomite, etc. Serpentine asbestus is not produced in the United States, but large amounts are annually imported from the Thetford and Coleraine mines of Quebec. Massive serpentine, or Verd Antique marble, is quarried at Milford, Conn.

Uses.—It takes a fine polish, and is used for ornamental work, as table-tops, mantels, etc. The fibrous variety, chrysotile, is used as asbestus.

TALC.—Steatite, Soapstone.

COMPOSITION.—$H_2Mg_3(SiO_3)_4$.

GENERAL DESCRIPTION.—A soft, soapy material, occurring foliated, massive, and fibrous, with somewhat varying hardness. Usually white, greenish or gray in color. Crystals almost unknown.

Physical Characters. H., 1. Sp. gr., 2.55 to 2.87.

LUSTRE, pearly or wax-like.	TRANSLUCENT.
STREAK, white.	TENACITY, sectile.
COLOR, white, greenish, gray, brown, red.	
CLEAVAGE, into non-elastic plates.	FEEL, greasy.

BEFORE BLOWPIPE, ETC.—Splits and fuses on thin edges to white enamel. With cobalt solution, becomes pale pink. Insoluble in acid.

VARIETIES.

Foliated Talc.—H = 1. White or green in color. Cleavable into non-elastic plates.

Soapstone or Steatite.—Coarse or fine, gray to green, granular masses. H., 1.5 to 2.5.

French Chalk.—Soft, compact masses, which will mark cloth.

Agolite.—Fibrous masses of H. 3 to 4.

Rensselaerite.—Wax-like masses. H., 3 to 4. Pseudomorphous after pyroxene.

SIMILAR SPECIES.—Softer than micas or brucite or gypsum. Further differentiated by greater infusibility, greasy feel, and the flesh-color obtained with cobalt solution.

REMARKS.—Talc is an alteration product of pyroxene, amphibole, muscovite, enstatite, etc., and occurs with dolomite, serpentine, magnesite, tourmaline, etc. An immense deposit at Gouverneur, N. Y., is mined, and the total output is ground for use in paper-making, etc. Large soapstone quarries are worked at Francestown, N. H. Chester, Saxon's River, Cambridgeport and Perkinsville, Vt., Cooptown, Md., and Webster, N. C. Massachusetts, New Jersey, Pennsylvania, Virginia and Georgia are also producing States.

USES.—Soapstone is cut in slabs for hearths, linings of stoves, sinks and other articles of refractory nature. It is ground and moulded into gas-tips, and used as a preparation for blackboards and as a fine quality of tinted plastering. Agolite is used to mix

with wood pulp in paper manufacture. Talc is used in soap, as a dressing for fine skin and leather, as a lubricant and as pencils, tailors' chalk, etc.

SEPIOLITE.—Meerschaum.

COMPOSITION.—$H_4Mg_2Si_3O_{10}$.

GENERAL DESCRIPTION.—Soft compact white, earthy to clay-like masses, of very light weight. Rarely fibrous.

Physical Characters. H., 2 to 2.5. Sp. gr., 1 to 2.

LUSTRE, dull. OPAQUE.
STREAK, white. TENACITY, brittle.
COLOR, white, gray, rarely bluish-green. FEEL, smooth.

BEFORE BLOWPIPE, ETC.—Blackens, yields odor of burning and fuses on thin edges. In closed tube yields water. With cobalt solution becomes pink. In hydrochloric acid gelatinizes.

SIMILAR SPECIES.—Resembles chalk, kaolinite, etc., but is characterized by lightness and gelatinization with acids.

REMARKS.—Possibly formed from Magnesite. The name "meerschaum" refers to the fact that it will float on water when dry. Most of the material used for pipes is obtained from Turkey. It occurs in large amount in Spain, and in smaller quantities in Greece, Morocco and Moravia. There are no productive American localities.

USES.—As material for costly tobacco pipes. In Spain it is a building stone. In Algeria it is used as a soap.

KAOLINITE —Kaolin, China Clay.

COMPOSITION. $H_4Al_2Si_2O_9$, with more or less iron, silica, and organic matter.

GENERAL DESCRIPTION.—Compact and clay-like or loose and mealy masses of pure white, yellow, brown, red and blue color. Also in white, scale-like crystals, with the lustre of satin. Usually unctuous and plastic.

Physical Characters. H., 2 to 2.5. Sp. gr., 2.6 to 2.63.

LUSTRE, dull or pearly. OPAQUE or translucent.
STREAK, white or yellowish. TENACITY, brittle.
COLOR, white, yellow, brown, red and blue.

BEFORE BLOWPIPE, ETC.—Infusible. Yields water in closed tube. With cobalt solution, becomes deep blue. Decomposed by sulphuric acid, but insoluble in nitric or hydrochloric acids.

SIMILAR SPECIES.—It is not harsh like infusorial earth and is softer than bauxite.

REMARKS.—Kaolinite is formed by alteration of feldspars and other silicates. Carbonated waters remove the basic oxides and part of the silica. Its associates are feldspars, corundum, diaspore, topaz, etc. In the United States kaolinite is mined at Okahumka, Lake County, Florida, at Sylva, Dilsboro and Webster, N. C., and at several places in New Castle County, Del., and Chester and Delaware Counties, Pa. Kaolin of poorer quality is obtained in Ohio and New Jersey, and many other deposits are known throughout the Atlantic States.

USES.—It is the chief constituent of porcelain, chinaware, ornamental tiles, etc.

FIG. 579.

Pyrophyllite, Lincoln Co., Ga. N. Y. State Museum.

PYROPHYLLITE.—Pencil Stone.

COMPOSITION.—$HAl(SiO_3)_2$.

GENERAL DESCRIPTION.—Radiated foliæ or fibres and compact masses of soapy feeling and soft and smooth like talc.

PHYSICAL CHARACTERS.—Translucent to opaque. Lustre, pearly or dull. Color, white, greenish, brownish or yellow. Streak, white. H., 1 to 2. Sp. gr., 2.8 to 2.9. Flexible.

BEFORE BLOWPIPE, ETC.—Whitens and fuses on the edges, and often swells and spreads like a fan. In closed tube yields water. Partially soluble in sulphuric acid.

REMARKS.—Occurs in large beds and as gangue of cyanite.

USES.—Extensively manufactured into slate pencils.

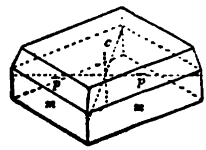
TITANO-SILICATES.

TITANITE. — Sphene.

COMPOSITION. — $CaSiTiO_5$.

GENERAL DESCRIPTION. — Brown, green or yellow, wedge-shaped or tabular monoclinic crystals, with adamantine or resinous lustre. Also compact, massive. Rarely lamellar.

FIG. 580.



Diana, N. Y.

CRYSTALLIZATION. — Monoclinic. $\beta = 60° 17'$. Axes $\grave{a} : \bar{b} : \grave{c} = 0.755 : 1 : 0.854$. Crystals very varied. The most common forms are: pinacoids c and a, unit prism m, negative unit pyramid $\bar{p}$, domes $x = (\grave{a} : \infty \bar{b} : \frac{1}{2}c)$; $\{102\}$, and $s = (\infty \grave{a} : \bar{b} : 2c)$; $\{021\}$, and the pyramid $l = (\grave{a} : \bar{b} : \frac{1}{2}c)$; $\{112\}$. Supplement angles are: $mm = 66° 29'$; $pp = 43° 49'$; $ll = 46° 7'$.

Optically +. Axial plane the plane of symmetry. Very large dispersion producing peculiar interference figure with many lemniscates and colored hyperbolæ.

Physical Characters. H., 5 to 5.5. Sp. gr., 3.4 to 3.56.

LUSTRE, adamantine or resinous. TRANSPARENT to opaque.
STREAK, white. TENACITY, brittle.
COLOR, brown to black, yellow, green, rarely rose-red.
CLEAVAGE, prismatic easily, pyramidal less easily.

BEFORE BLOWPIPE, ETC.—Fuses, with intumescence, to a dark glass, sometimes becoming yellow before fusion. In salt of phosphorus after reduction, the bead is violet. Partly soluble in hydrochloric acid, completely so in sulphuric acid.

REMARKS.—Occurs both as original and secondary mineral derived from alteration of menaccanite, brookite, etc. Its associates are pyroxene, amphibole, feldspars, zircon, iron ores, apatite, etc. Good gem stones have been found at Brewsters, N. Y.; Bridgewater, Pa., and Magnet Cove, Ark.

USES.—As a gem.

PART IV.

DETERMINATIVE MINERALOGY.

CHAPTER XXXVII.

TABLES FOR RAPID DETERMINATION OF THE COMMON MINERALS.

In the tables which follow, the minerals are divided first into minerals of metallic lustre and minerals of non-metallic lustre. The minerals of metallic lustre are divided into forty-eight groups by eight horizontal divisions, based on color and hardness, and six vertical divisions based on the effect of the blowpipe flame on charcoal.

From the minerals of non-metallic lustre a division, *A*, of minerals possessing a taste, that is, soluble in water, is set aside. The non-metallic minerals without taste, as Division B and C, are then divided into forty-four groups, the action of hydrochloric acid giving, in each, four horizontal divisions, and the action upon charcoal, in *B*, and in the platinum forceps, in *C*, giving the vertical divisions.

The species in each group are printed in heavy type or ordinary type, according to their importance. The symbols I., T., H., O., M., Tri. before each name designate the system of crystallization. The formula following is expected to suggest confirmatory blowpipe tests and the lines of fine type to suggest distinctive test or characters. H signifies hardness, G, specific gravity, S. Ph., salt of phosphorus. The page reference to the complete description of the species is also given.

For accurate results these precautions must be taken:

1. All tests should be made upon homogeneous material, preferably crystalline, as the tests may be unreliable if the material is impure, *unless the effect of the impurity upon the test is known.*

2. The classifying tests must be *decided*, and, if weak, should be attributed either to improper manipulation or to the presence of some accidental impurity.

3. The lustre must be observed on a fresh fracture.

4. The determination must be confirmed by reference to the description of the species, and, when possible, by comparison with known specimens.

5. When the test is very close to a line of division it is better to look for the mineral upon both sides of the line.

If, as may happen, a specimen belongs to a rare species not included in the scheme, its tests and description will not correspond to any species therein and more elaborate tables will be needed.

TABLE I.—MINERALS OF META

The Mineral He

		GIVES GARLIC ODOR.	GIVES WHITE COATING BUT NO GARLIC ODOR.	GIVES YELLOW COATING N THE ASSAY ON CONTINUED B
The Color is Silver-White, Tin-White or Gray.	Distinctly Scratched by Calcite.		H. **Molybdenite**, p. 278, MoS_2 Soapy feel. Streak greenish. O. **Stibnite**, p. 273, Sb_2S_3 Easy fusion. Dark-gray color. **Blue-green flame.** **Gold Telluride**, p. 306, $(Au,Ag)Te_2$ Residue yellow. White sublimate is made rose by H_2SO_4 H. Tellurium, p. 361, Te. No residue. I. **Hessite**, p. 296, Ag_2Te Residue white (silver).	— Lead, p. 256, Pb H. Tetradymite, p. 268, Bi_2(T Bluish-green flame. O. Bismuthinite, p. 268, Bi_2S_3 Needles or masses. G = 6.4 O. Jamesonite, p. 259, Pb_2Sb_2 Fibres or needles. G = 5.5 H. **Bismuth**, p. 267, Bi. Arbo O. Aikinite, p. 268, PbCuBiS Embedded prisms or mass I. **Galenite**, p. 256, PbS Cubic cleavage. G = 7.4 to
	Distinctly Scratched by a Knife.	H. Arsenic, p. 270, As Brittle. Blue flame. H. Antimony, p. 273, Sb Thick fumes. Green flame. I. **Tetrahedrite**, p. 286, $Cu_8Sb_2S_7$ See opposite.	H. Antimony, p. 273, Sb Brittle. Thick fumes. I. Stannite, p. 249, (Cu,Sn,Fe)S Coat blue by cobalt solution. I. **Tetrahedrite**, p. 286, $Cu_8Sb_2S_7$ Black Streak. Color dark gray.	O. Bournonite, p. 258, CuPbSb Simple and cog-wheel crys G = 5.7 to 5.9. I. Clausthalite, p. 259, PbSe Odor of horse-radish.
	Not Distinctly Scratched by a Knife.	**In closed tube.** O. Leucopyrite p. 215, Fe_3As_4 Black sublimate. I. **Cobaltite**, p. 284, CoAsS, unalt'd. I. **Smaltite**, p. 285, $(Co,Ni)As_2$ Black sublimate. I. Chloanthite, p. 286, $(Ni,Co)As_2$ Black sublimate. O. **Arsenopyrite**, p. 214, FeAsS Red sublimate, then black.		
The Color is Black or Nearly Black.	Distinctly Scratched by Calcite.		O. **Stibnite**, p. 273, Sb_2S_3 Very easy fusion. O. **Stephanite**, p. 300, Ag_5SbS_4 Black streak. Fuses leaving Ag. M. Polybasite, p. 301, $(Ag,Cu)_9SbS_6$ Black streak. Cu with S.Ph. H. **Pyrargyrite**, p. 299, Ag_3SbS_3 Purplish-red streak.	I. **Galenite**, p. 256, PbS Cubic cleavage. G = 7.4 to
	Dist'ly Scr'd by a Knife.	O. **Enargite**, p. 286, Cu_3AsS_4 Columnar. I. Tennantite, p. 288, $Cu_8As_2S_7$ Granular.	I. **Tetrahedrite**, p. 286, $Cu_8Sb_2S_7$ Tetrahedral or fine-grained. I. **Sphalerite**, p. 242, ZnS Pale-brown streak.	
	Not Distinctly Scratched by a Knife.		I. **Franklinite**, p. 217, $(FeMnZn)_3O_4$ Brown-streak. White coat.	I. **Uraninite**, p. 276, U,Pb,T Botryoidal. Green bead S. R. F.
Yellow, Red, Bronze.	Distinctly Scratched by a Knife.	H. **Niccolite**, p. 289, NiAs Color, copper-red. Streak black.	O. **Gold Telluride**, p. 306, $(AgAu)Te_2$. Color brass-yellow.	
	Not S'd by Knife.			

C OR SUBMETALLIC LUSTRE.

on Charcoal:

Gives Magnetic Residue but no Coating or Garlic Odor.	Gives Non-Magnetic Metal but no Coating or Garlic Odor.	Not Previously Included.
	O. Stromeyerite, p. 298, $(Ag,Cu)_2S$ I. Amalgam, p. 298, AgHg Whitens copper.	—, Mercury, p. 298, Hg. Fluid globules. Entirely volatilized.
I. **Platinum**, p. 308, Pt(Fe) Grains and scales. G. 14 to 19. I. Iron, p. 208, Fe. Grains and masses. G. 7.3 to 7.8.	I. **Silver**, p. 296, Ag Malleable. Silver streak. G = 10 to 11. I. **Platinum**, p. 308, Pt Grains and scales. G = 14 to 19.	
I. **Linnæite**, p. 288, $(Co,Ni)_3S_4$ Octahedrons or massive.	H. Iridosmine, p. 308, (Ir,Os) Flat grains. H = 6 — 7.	
	I. **Argentite**, p. 297, Ag_2S Sectile. Residue of silver. M. Tenorite, p. 289, CuO Minute scales or earthy masses.	H. **Graphite**, p. 368, C Soapy feel. Shining streak. O. **Pyrolusite**, p. 229, MnO_2 Radiating or compact. Black streak. Scratched by finger nail.
	O. **Chalcocite**, p. 283, Cu_2S Brittle. Residue of copper.	I. Alabandite, p. 228, MnS Cubic cleavage. Green streak. O. **Manganite**, p. 230, MnO(OH) Prismatic. Dark-brown streak.
—, Turgite, p. 220, $Fe_4O_5(OH)_2$ Red Streak. Decrepitates. O. Goethite, p. 220, FeO(OH) Yellow streak. Crystalline. —, **Limonite**, $Fe_2O_3,Fe_2(OH)_6$ Yellowish-brown streak, p. 221. M. **Wolframite**, (Fe.Mn)WO_4 Fuses easily. G=7.2 to 7.5, p. 225. H. **Hematite**, p. 217, Fe_2O_3 Red streak. Brilliant lustre. H. **Ilmenite**, p. 219. (Fe.Mg)$OTiO_2$ Red or black streak. Violet S.Ph. in R. F. I. **Magnetite**, p. 215, Fe_3O_4 Black streak. Magnetic. I. **Franklinite**, $(FeMnZn)_3O_4$ Brown streak. White coat, p. 217. I. **Chromite**, p. 224, $FeCr_2O_4$ Brown streak. Green in S.Ph.		O. Columbite, p. 225, $Fe(CbO_3)_2$ Brilliant lustre. G = 5.3 to 7.3. I. **Uraninite**, p. 276, U,Pb,Th, etc. Botryoidal. Green S.Ph. in R.F. —. **Psilomelane**, p. 231, H_4MnO_5 Botryoidal. Brownish-black streak. T. Hausmannite, p. 229, Mn_3O_4 Twin pyramids. Chestnut-brown streak. T. **Braunite**, $Mn_2O_3.MnSiO_3$ Black streak. Gelatinizes, p. 228. T. **Rutile**, p. 251, TiO_2 Violet bead S.Ph. in R.F. O. Brookite, p. 252, TiO_2 I. **Chromite**, p. 224, $FeCr_2O_4$ Brown streak. Green in S.Ph.
I. **Bornite**, p. 284, Cu_3FeS_3 Red-bronze fracture. H. **Millerite**, p. 288, NiS Brassy needles or hair. I. **Pentlandite**, p. 288, (Fe,Ni)S Light bronze-yellow. T. **Chalcopyrite**, p. 284, $CuFeS_2$ Deep brass-yellow. H. **Pyrrhotite**, p. 209, Fe_nS_{n+1} Brown-yellow. Magnetic.	I. **Gold**, p. 304, (Au,Ag) Golden streak. Malleable. I. **Copper**, p. 282, Cu Copper streak. Malleable. I. **Cuprite**, p. 288, Cu_2O Brownish-red streak. Brittle.	
I. **Pyrite**, p. 210, FeS_2 O. **Marcasite**, p. 212, FeS_2		

TABLE II.—MINERALS OF

A. Minerals with Decided Ta

NAME.	TASTE.	IN THE FORCEPS O. F. THE FLAME IS COLORED.	TH
Tri. **Sassolite**, p. 356, H_3BO_3	Acid, slightly saline.	Yellowish green.	
M. **Mirabilite**, p. 314, $Na_2SO_4+10H_2O$	Bitter, cooling.	Yellow.	
O. Mascagnite, p. 318, $(NH_4)_2SO_4$	Bitter, pungent.		
O. Epsomite, p. 340, $MgSO_4+7H_2O$	Bitter and salt.		
H. Aphthitalite, p. 311, $(K.Na)_2SO_4$	Bitter and salt.	Violet.	
M. **Borax**, p. 356, $Na_2B_4O_7+10H_2O$	Alkaline, sweetish.	Yellow.	
M. Trona, p. 315, $Na_2CO_3.NaHCO_3+2H_2O$	Alkaline.	Yellow.	
M. Alunogen, p. 351, $Al_2(SO_4)_3+18H_2O$	Astringent.		
M. Melanterite, p. 223, $FeSO_4 7H_2O$	Astringent, sweetish.		
O. Goslarite, p. 242, $ZnSO_4+7H_2O$	Astringent, nauseous.		
I. Kalinite, p. 311, $KAl(SO_4)_2+12H_2O$	Astringent.	Violet.	
Tri. Chalcanthite, p. 289, $CuSO_4+5H_2O$	Astringent, nauseous.	Emerald green.	
M. **Copiapite**, p. 222, $Fe_2Fe(OH)_2(SO_4)_5 18H_2O$	Astringent, nauseous.		
H. **Soda Nitre**, p. 314, $NaNO_3$	Saline, cooling.	Yellow.	
I. Sal Ammoniac, p. 318, NH_4Cl	Saline.		
O. **Nitre**, p. 311, KNO_3	Saline, cooling.	Violet.	
I. Sylvite, p. 310, KCl or Carnallite $KCl.MgCl.6H_2O$	Saline.	Violet.	
O. Thenardite, p. 314, Na_2SO_4	Saline.	Yellow.	
I. **Halite**, p. 312, NaCl	Saline.	Yellow.	
M. Glauberite, p. 314, $Na_2SO_4CaSO_4$	Saline.	Yellow.	
M. **Kainite**, p. 310, $MgSO_4KCl+3H_2O$	Saline.	Violet.	

B. The Mineral is Without Taste, but strongl

The Mineral, in finest Powder, Boiled with Hydrochloric Acid.		YIELDS ARSENICAL ODOR.	YIELDS WHITE COATING BUT NO ARSENICAL ODOR.	YIELDS YE… ARS…
	Is Dissolved with Effervescence.		—. Hydrozincite, p. 244, $Zn_3CO_3(OH)_4$ H. 2 to 2.5. Chalky or pearly. T. Phosgenite, p. 263, $(PbCl)_2CO_3$ Yellow coat with Bi flux. I. **Sphalerite**, p. 242, ZnS Evolution H_2S. Brown to black color. H. **Smithsonite**, p. 244, $ZnCO_3$ H. 5. Vitreous, botryoidal, drusy.	O. **Cerussite**, p Greenish yello —. Bismutite, p Chocolate and
	Dis'l'd Forms Jelly.		O. **Calamine**, p. 246, $(ZnOH)_2SiO_3$ Water in closed tube. H. **Willemite**, p. 245, Zn_2SiO_4 Anhydrous.	
	Is Dissolved without Effervescence or Formation of Jelly.	**Magnetic Residue.** M. Annabergite, p. 239, $Ni_3(AsO_4)_2+8H_2O$ Apple green crusts or fibers. M. Erythrite, p. 236, $Co_3(AsO_4)_2+8H_2O$ Crimson fibers and prisms. **Non-Magnetic Residue.** H. Mimetite, p. 262, $Pb_5Cl(AsO_4)_3$ Prisms or globular groups. O. Olivenite, p. 290, $Cu_2(OH)AsO_4$ Olive green to brown crystals and fibers.	O. Valentinite, p. 275, Sb_2O_3 White silky prisms or fibers. I. Senarmonite, p. 275, Sb_2O_3 Pearl gray octahedrons. M. Kermesite, p. 275, Sb_2S_2O Cherry red tufts or fibers. O. Molybdite, p. 278, MoO_3 Yellow powder, usually. H. **Zincite**, p. 248, ZnO Dark red, cleavable or grains. O. Atacamite, p. 289, $Cu_2(OH)_3Cl$ Deep emerald green. Blue flame mixed with green.	—. Bismite, p. 2 Yellow to whit —. Minium, p. 2 Vivid red powd M. Crocoite, p. Hyacinth red c H. **Pyromorph** Green or brow H. **Vanadinite** Red or brown p O. Descloizite, p Drusy. Black. T. **Wulfenite**, Yellow or brow
	Is Insoluble or Nearly Insoluble.	H. **Proustite**, p. 299, Ag_3AsS_3 Color and streak scarlet vermilion. O. **Orpiment**, p. 271, As_2S_3 Color and streak lemon yellow. M. **Realgar**, p. 271, AsS Streak orange red, color darker.	H. **Pyrargyrite**, p. 299, Ag_3SbS_3 Color nearly black, streak purplish red. T. Calomel, p. 294, Hg_2Cl_2 Completely volatilized.	O. **Anglesite**, p Colorless to wh M. Linarite, p. Deep blue cryst

ɪON-METALLIC LUSTRE.

e, that is, Soluble in Water.

'LAME IS NOT COLORED. EATED ON COAL THE MINERAL:	HARDNESS.	REMARKS.
	1	White pearly scales, smooth feel.
	1.5 to 2	White efflorescent crusts.
ields white fumes.	2 to 2.5	Gray mealy crusts and stalactites.
elts, becomes infusible.	2 to 2.5	White massive or silky fibers.
	3 to 3.5	Delicate crystals on lava, or crusts.
	2 to 2.5	White crystals resembling those of pyroxene, or crusts.
	2.5 to 3	White glistening crusts or beds.
elts, becomes infusible.	1.5	White silky fibers or crusts.
ecomes magnetic.	2	Pale green efflorescence on sulphide of iron.
ields white fumes.	2 to 2.5	White alteration on or near sphalerite.
	2 to 2.5	White efflorescence on clay minerals.
	2.5	Blue crystals or masses.
ecomes magnetic.	2.5	Yellow scales or granular masses.
	1.5 to 2	Deliquescent crusts.
ields white fumes.	1.5 to 2	White crystals or incrusting.
	2	Acicular crystals or tufts. Not altered by exposure.
	2 to 3	Colorless cubes or white masses.
	2 to 3	White crossed and simple crystals.
	2.5	White or brown cubes or masses.
	2.5 to 3	Gray tabular crystals. Efflorescence on long exposure.
	2.5 to 3	White to red granular masses.

heated on Charcoal in the Reducing Flame:

W COATING BUT NO ICAL ODOR.	VOLATILIZES, NOT PREVIOUSLY INCLUDED.	YIELDS MAGNETIC RESIDUE BUT IS NON-VOLATILE.
62, $PbCO_3$ oat with Bi flux. 9, $BiO.Bi(OH)_2CO_3$ coat with Bi flux.	H. Greenockite. p. 247, CdS Iridescent tarnish on coal.	H. **Siderite**, p. 226, $FeCO_3$ Sp. Gr. 3.8 to 3.9. Brown. H. Ankerite, p. 337, $(Ca,Mg,Fe)CO_3$ Sp. Gr. 2.9 to 3.1. Gray to brown. H. **Rhodochrosite**, p. 231, $MnCO_3$ Sp. Gr. 3.3 to 3.6. Pink to red.
		M. Allanite, p. 408, $R''_3R_2(SiO_4)_3$
Bi_2O_3 owder or mass. , Pb_3O_4 , $PbCrO_4$ stals, orange streak. e, p. 260, $Pb_5Cl(PO_4)_3$ risms, often parallel.). 264, $Pb_5Cl(VO_4)_3$ sms, often hollow. 65, $(Pb,Zn)(PbOH)VO_4$ rown or red. 265, $PbMoO_4$ quare plates or pyramids.		—. **Garnierite**, p. 240, $H_2(Ni,Mg)SiO_4+H_2O$ Deep green to pale green. Soft and friable. O. Hypersthene, p. 384, $(Mg,Fe)SiO_3$ Foliated, metalloidal. M. Vivianite, p. 223, $Fe_3(PO_4)_2+8H_2O$ Blue color and streak. **Streak yellow to brown.** —. **Limonite**, p. 221, $Fe_2O_3.Fe_2(OH)_6$ Earthy to compact or fibrous. O. Goethite, p. 220, $FeO(OH)$ Needles, scales and velvet crusts. **Streak Red.** Turgite, p. 220, $Fe_4O_5(OH)_2$ In closed tube flies to pieces. H. **Hematite**, p. 217, Fe_2O_3 In closed tube unchanged.
259, $PbSO_4$ crystals or massive. , $[(PbCu)OH]_2SO_4$.	O. **Sulphur**, p. 360, S Burns with blue flame and odor SO_2 H. **Cinnabar**, p. 294, HgS volatilized. **Fused in Matrass with $KHSO_4$** I. **Cerargyrite**, p. 301, AgCl Globule, yellow hot, white cold. I. Embolite, p. 302, Ag(ClBr) I. Bromyrite, p. 302, AgBr Globule red hot, yellow cold. H. Iodyrite, p. 302, AgI Violet vapor, globule dark red hot.	M. **Biotite**, p. 418. Black micaceous. M. **Chlorite**, p. 419, H.FeMgAlSi M. **Pyroxenes**, p. 385, rich in iron. Angle of prism 87° 10′. M. **Amphiboles**, p. 389, rich in iron. Angle of prism 124° 11′. I. **Garnets**, p. 396, Andradite, Almandite. M. **Epidote**, $Ca_2(Al.Fe)_2(AlOH)(SiO_4)_3$ Green grains, fibers or crystals. P. 406.

TABLE II.—MINERALS WITH

C. If the Mineral is Tasteless, Non-Volatile and not Made Magneti

The Mineral in Finest Powder, Boiled with Hydrochloric Acid		Fuses Easily to a White Glass or Enamel.	Fuses Easily to a Colorless Glass.	Fuses Easily to a Colored Glass or Enamel.
	Is Dissolved with Effervescence.	O. **Witherite**, p. 320, $BaCO_3$ Colors flame yellowish green. M. Gaylussite, $CaNa_2(CO_3)_2+5H_2O$ Intense yellow flame. P. 315. H. Cancrinite, $R(Na_2CO_3)(SiO_4)$ Forms a jelly on heating. P. 395.		M. **Azurite**, $Cu_3(OH)_2(CO_3)_2$ Deep blue color. P. 290. M. **Malachite**, $Cu_2(OH)_2CO_3$ Bright green color. P. 290.
	Is Dissolved with Formation of Jelly.	M. Pectolite, p. 387, $HNa_2Ca(SiO_3)_3$ Radiating splintery fibers. O. Thomsonite, $(Na_2Ca)Al_2Si_2O_8$ P. 416. $+\frac{5}{2}H_2O$ M. **Wollastonite**, p. 387, $CaSiO_3$ T. **Apophyllite**, p. 413, $H_{14}K_2Ca_8(SiO_3)_{16}9H_2O$ Swells, colors flame violet. H. **Chabazite**, p. 414, $(Ca,Na_2)Al_2(SiO_4)_4+6H_2O$ Intumesces. Nearly cubic. I. Haüynite, p. 395, $8(Na_2Ca)Al_2SO_4(SiO_3)_4$ Rounded grains. Sulphur react. I. Lazurite, p. 396, $Na_4(NaS_3Al)Al_2(SiO_4)_3$ Intumesces. Deep blue color.	M. **Datolite**, p. 405, $Ca(BOH)SiO_4$ Intumesces. Green flame. I. **Analcite**, $NaAl(SiO_3)_2).H_2O$ Quiet fusion, yellow flame. P. 415. O. **Natrolite**, p. 416, $Na_2Al_2Si_3O_{10}$ $+2H_2O$ Quiet fusion. Slender prisms. H. **Nephelite**, $Na_8Al_8Si_9O_{34}$ Strong yellow flame. Glassy or with greasy luster. P. 395.	E. Mellilite, Si,Al,Fe,Mg,Na,Ca,O Fuses with intumescence to green or yellow glass. P. 402.
	Is Dissolved without Effervescence or Formation of Jelly.	M. **Cryolite**, p. 346, $AlNa_3F_6$ Yellow flame. $H=2.5$. T. **Wernerite**, $Ca,Na,Al.SiO_4$ Yellow flame. $H=5$ to 6. P. 400. I. **Fluorite**, p. 325, CaF_2 Red flame. Cubic, phosphorescent. M. **Gypsum**, p. 328, $CaSO_4+2H_2O$ Pale red flame. Water test. $H=2$. O. **Anhydrite**, p. 327, $CaSO_4$ Pale red flame. $H=3$. I. Boracite, p. 359, $Mg_7Cl_2B_{16}O_{30}$ Green flame. Violet by Co solution. M. **Stilbite**, $H_4R_2Al_2(SiO_3)_6+4H_2O$ Sheaf-like. Swells with heat. P. 414. M. Heulandite, p. 414, $H_4CaAl_2(SiO_3)_6+3H_2O$ Swells with heat. O. **Prehnite**, $H_2Ca_2Al_2(SiO_4)_3$ Usually green. $H=6$ to 6.5. P. 408.	—. **Ulexite**, $NaCaB_5O_9+8H_2O$ Yellow flame. $H=1$. Silky. P. 357. Tri. **Plagioclase**, (labradorite) p. 381. $NaAlSi_3O_8.nCaAl_2Si_2O_8$ Partially soluble. $H=6$. M. **Colemanite**, $Ca_2B_6O_{11}+5H_2O$ Exfoliates. Flame green. P. 357.	**Flame is colored blue.** O. Atacamite, p. 289, $Cu_2(OH)_3Cl$ Deep emerald green. **Flame is colored emerald green.** O. Libethenite, p. 289, $Cu_2(OH)PO_4$ Dark to olive green crystals. O. Brochantite, $CuSO_4 3Cu(OH)_2$ Emerald green needle crystals. P. 289. I. **Cuprite**, p. 288, Cu_2O Deep red to brownish red. T. Torbernite. Pearly green plates. P. 277. $Cu(UO_2)_2(PO_4)_2+8H_2O$ **Flame not colored.** O. Autunite, $Ca(UO_2)_2(PO_4)_2.8H_2O$ Pearly yellow plates. P. 277. T. **Vesuvianite**, p. 401, $Ca_6[Al(OH,F)]Al_2(SiO_4)_5$ O. **Prehnite**, p. 408. Tri. **Rhodonite**, p. 387, $MnSiO_3$ Red, fuses black.
	Is Insoluble or Nearly Insoluble.	Tri. **Plagioclase**, p. 381, $n(NaAlSi_3O_8)m(CaAl_2Si_2O_8)$ Yellow flame. $H=6$. M. Petalite, p. 378, $AlLi(Si_2O_5)_2$ Red flame. Phosphorescent. $G=2.4+$ Tri. Amblygonite, p. 316, $Li(AlF)PO_4$ Intumesces. Red flame. O. **Celestite**, p. 321, $SrSO_4$ Red flame. $G=3.9+$ M. Lepidolite, p. 317, $R_3Al(SiO_3)_3$ Red flame. Micaceous. O. **Barite**, p. 319, $BaSO_4$ Green flame. $G=4.3$. O. Zoisite, $Ca_2(AlOH)Al_2(SiO_4)_3$ Columnar. No flame. P. 406. H. **Tourmaline**, $R_{13}B_2(SiO_5)_4$ P. 409. M. **Pyroxene**, p. 385, $RSiO_3$ M. **Amphibole**, p. 389, $RSiO_3$ H. **Beryl**, p. 391, $Be_3Al_2(SiO_3)_6$	Tri. **Plagioclase**, p. 381, $n(NaAlSi_3O_8)$ $CaAl_2Si_2O_8$ Yellow flame. $H=6$. M. **Spodumene**, $LiAl(SiO_3)_2$ Red flame. Splits in thin plates. P. 316. M. **Pyroxene** (Diopside), p. 385, $CaMgSi_2O_6$ M. **Amphibole**, p. 389 (Tremolite), $CaMg_3Si_4O_{12}$ M. Jadeite, p. 386, $NaAlSi_2O_6$ Yellow flame. Compact. M. Glaucophane, p. 390, $NaAl(SiO_3)_2(Fe,Mg)SiO_3$ Yellow flame. Massive.	T. **Vesuvianite**, p. 401, $Ca_6(AlOHF)Al_2(SiO_4)_5$ Brown to bright green crystals and columns. M. **Titanite**, p. 424, $CaSiTiO_5$ Wedge-shaped crystals. Boiled with Sn and HCl violet. M. **Epidote**, $Ca_2Al_2(AlOH)(SiO_4)_3$ Yellow green grains, fibers and crystals. P. 406. I. **Garnet**, p. 396, Spessartite, $Mn_3Al_2(SiO_4)_3$ and Pyrope, $Mg_3Al_2(SiO_4)_3$ M. **Pyroxene**, $(Ca,Mg,Fe)SiO_3$ Cleavage and prism angle 87°. P. 385. M. **Amphibole**, p. 389, Actinolite $Ca(Mg,Fe)_3(SiO_3)_4$ Cleavage and prism angle 125°. Tri. Axinite, $H_2R_4(BO)Al_2(SiO_4)_5$ P. 408. Clove-brown, acute edged crystals H. **Tourmaline**, p. 409, $R_{18}B_2(SiO_5)_4$ $H=7$ to 7.5. Hemimorphic. P.

OUT METALLIC LUSTRE.

c, a Fragment is Heated in the Forceps at Tip of Blue Flame.

FUSES WITH DIFFICULTY.	INFUSIBLE BUT IN POWDER MADE DEEP BLUE BY COBALT SOLUTION.	INFUSIBLE, NOT INCLUDED PREVIOUSLY.
M. **Barytocalcite**, p. 321, $(Ba,Ca)CO_3$ Colors flame yellowish green. O. **Strontianite**, p. 323, $SrCO_3$ Colors flame crimson.		H. **Magnesite**, p. 340, $MgCO_3$ White chalk-like masses. H. **Rhodochrosite**, p. 231, $MnCO_3$ Pink to red. **Red Flame.** H. **Calcite**, p. 333, $CaCO_3$ G. 2.71. Rhombohedral cleavage. O. **Aragonite**, p. 332, $CaCO_3$ G=2.95. H. **Dolomite**, p. 335, $CaCO_3.MgCO_3$ Slow effervescence of lumps.
M. **Wollastonite**, p. 387, $CaSiO_3$ Yellow-red flame. H 4.5 to 5. Tri. **Anorthite**, p. 382, $CaAl_2Si_2O_8$ Yellow-red flame. H 6 to 6.5. —. **Sepiolite**, p. 422, $H_4Mg_2Si_3O_{10}$ Compact, earthy. Pink with cobalt solution. O. **Calamine**, p. 246, $(ZnOH)_2SiO_3$ White coat with soda. Water in closed tube. H. **Willemite**, p. 245, Zn_2SiO_4 White coat with soda.		T. Thorite, p. 254, $ThSiO_4$ H=5. Orange to brown. H. Dioptase, p. 292, H_2CuSiO_4 H=5. Emerald green. O. **Chrysolite**, p. 398, $(Mg,Fe)_2SiO_4$ H=7. Olive to gray-green. M. Chondrodite, $H_2Mg_{19}Si_8O_{34}F_4$ H=6.5. Brown to yellow. P. 409.
H. **Apatite**, p. 330, $Ca_5(F,Cl)(PO_4)_3$ Red flame, green with H_2SO_4 T. **Scheelite**, p. 339, $CaWO_4$ In Ph. S. with R. F. bead blue when cold. M. **Colemanite**, $Ca_2B_6O_{11}+5H_2O$ Exfoliates. Flame green. P. 357. —. **Serpentine**, p. 420, $H_4Mg_3Si_2O_9$ H=4. Yields water. Lustre greasy. O. Iolite, $H_2(Mg,Fe)_4Al_8Si_{10}O_{37}$ H=7 to 7.5. Blue vitreous. P. 394.	M. Aluminite, p. 351, $Al_2SO_{11}.9H_2O$ H=1 to 2. White chalky masses. —. **Bauxite**, p. 346, $Al_2O(OH)_4$ Oölitic or like clay. O. **Wavellite**, p. 352, $Al_6(OH)_6(PO_4)_4+9H_2O$ Spheres and hemispheres of radiating crystals. —. **Turquois**, $Al_2(OH)_3PO_4.H_2O$ Sky blue to green with lustre of wax. P. 352. I. **Leucite**, p. 384, $KAl(SiO_3)_2$ Trapezohedrons. White or gray in color.	M. Monazite, p. 258, $(Ce,La,Di)(PO_4)$ Resinous brown crystals or yellow grains. H. **Brucite**, p. 340, $Mg(OH)_2$ Foliated or fibrous. Pink with Co. solution. —. Wad, p. 231, Mn oxides. Dull earthy brown to black. —. **Chrysocolla**, $CuSiO_3+2H_2O$ Green to sky-blue with waxy lustre. P. 291.
O. **Talc**, p. 421, $H_2Mg_3(SiO_3)_4$ H=1. Soapy. Pink with Co solution. —. Pyrophyllite, p. 423, $HAl(SiO_3)_2$ H=1 to 2. Soapy. Blue by Co solution. M. **Chlorite**, p. 419, $H(Mg,Fe)AlSiO$ H=1 to 2.5. Dark green. M. **Muscovite**, $H_2(K,Na)Al_3(SiO_4)_3$ H=2.5. Light colored mica. P. 417. M. **Phlogopite**, $R_3Mg_3Al(SiO_4)_3$ H=2.5. Mica in limestone. P. 419. M. **Biotite**, p. 418, $(KH)_2(Mg,Fe)_2Al_2(SiO_4)_3$ H=2.5. Dark mica in granites. O. Enstatite, p. 384, $(Mg,Fe)SiO_3$ H=5.5. Foliated. Pearly lustre. M. **Orthoclase**, p. 378, $KAlSi_3O_8$ H=6. Rectangular cleavage. Tri. Microcline, p. 380, $KAlSi_3O_8$ H=6. Striations frequent. H. **Tourmaline**, $R_{18}B_2(SiO_5)_4$ H=7 to 7.5. Hemimorphic. P. 409. H. **Beryl**, p. 391, $Be_3Al_2(SiO_3)_6$ H=7.5 to 8. Prismatic.	M. **Kaolinite**, p. 422, $H_4Al_2Si_2O_9$ H=2 to 2.5. Soapy feel. M. **Gibbsite**, p. 351, $Al(OH)_3$ H=2.5 to 3.5. Clay odor. H. **Alunite**, $K(AlO_2)_3(SO_4)_2+3H_2O$. H=3.5 to 4. Small white cuboids P. 351. Tri. **Cyanite**, p 392, $(AlO)_2SiO_3$ H=5. Blue bladed crystals. O. Sillimanite, p. 405, $Al(AlO)SiO_4$ H=6 to 7. Gray to brown crystals and fibers. O. Diaspore, p 349, $AlO(OH)$ H=6.5. Pearly, pink to brown. O. **Andalusite**, p. 404, $Al(AlO)SiO_4$ H=7 to 7.5. Square prisms. H. Phenacite, p. 399, Be_2SiO_4 H=7.5 to 8. Resembles quartz. I. **Spinel**, p. 341, $MgAl_2O_4$ H=8. Octahedrons. O. **Topaz**, p. 403, $Al(Al(OF_2)SiO_4$ H=8. Prisms with basal cleavage. O. **Chrysoberyl**, p. 353, $BeAl_2O_4$ H=8.5. Tabular, yellow or green. H. **Corundum**, p. 346, Al_2O_3 H=8-9. G=4. Adamantine.	T. Octahedrite, p. 252, TiO_2 Brown or blue pyramids. Adamantine. T. **Rutile**, p. 251, TiO_2 Red to black. Adamantine prismatic, often needles. G=4.2. T. **Cassiterite**, p. 249, SnO_2 Brownish-black. Adamantine, G=6.8 to 7.1. H. **Quartz**, p. 372, SiO_2 H=7. G=2.65. H. Tridymite, p. 376, SiO_2 Minute tabular crystals. —. **Opal**, p. 376, $SiO_2.nH_2O$ H=5.5 to 6.5. G=2.1 to 2.2. Fracture conchoidal. T. **Zircon**, p. 402, $ZrSiO_4$ H=7.5. Pyramid and prism. O. **Staurolite** p. 410, $Fe(AlO)_4(AlOH)(SiO_4)$ H=7.5. Prisms. Usually twinned. H. **Tourmaline**, $R_{18}B_2(SiO_5)_4$ H=7.5. Hemimorphic. P. 409. I. **Garnet**, p. 396, Uvarovite, $Ca_3Cr_2(SiO_4)_3$ H=7.5. Emerald green crystals. I. **Diamond**, p. 366, C H=10. Adamantine. G=3.51.

INTERNATIONAL ATOMIC WEIGHTS.

		O = 16.	H = 1.			O = 16.	H = 1.
Aluminium	Al	27.1	26.9	Neodymium	Ne	143.6	142.5
Antimony	Sb	120.2	119.3	Neon		20	19.9
Argon	A	39.9	39.6	Nickel	Ni	58.7	58.3
Arsenic	As	75.0	74.4	Nitrogen	N	14.04	13.93
Barium	Ba	137.4	136.4	Osmium	Os	191	189.6
Beryllium (Glucinum)	Be	9.1	9.03	Oxygen	O	16.00	15.88
Bismuth	Bi	208.5	206.9	Palladium	Pd	106.5	105.7
Boron	B	11	10.9	Phosphorus	P	31.0	30.77
Bromine	Br	79.96	79.36	Platinum	Pt	194.8	193.3
Cadmium	Cd	112.4	111.6	Potassium	K	39.15	38.86
Cæsium	Cs	133	132	Praseodymium	Pr	140.5	139.4
Calcium	Ca	40.1	39.8	Radium	Ra	225	223.3
Carbon	C	12.00	11.91	Rhodium	Rh	103.0	102.2
Cerium	Ce	140	139	Rubidium	Rb	85.4	84.8
Chlorine	Cl	35.45	35.18	Ruthenium	Ru	101.7	100.9
Chromium	Cr	52.1	51.7	Samarium	Sm	150	148.9
Cobalt	Co	59.0	58.56	Scandium	Sc	44.1	43.8
Columbium (Niobium)	Cb	94	93.3	Selenium	Se	79.2	78.6
Copper	Cu	63.6	63.1	Silicon	Si	28.4	28.2
Erbium	E	166	164.8	Silver	Ag	107.93	107.12
Fluorine	F	19	18.9	Sodium	Na	23.05	22.88
Gadolinium	Gd	156	155	Strontium	Sr	87.6	86.94
Gallium	Ga	70	69.5	Sulphur	S	32.06	31.83
Germanium	Ge	72.5	71.9	Tantalum	Ta	183	181.6
Gold	Au	197.2	195.7	Tellurium	Te	127.6	126.6
Helium	He	4	4	Terbium	Tb	160	158.8
Hydrogen	H	1.008	1.000	Thallium	Tl	204.1	202.6
Indium	In	114	113.1	Thorium	Th	232.5	230.8
Iodine	I	126.85	125.90	Thulium	Tm	171	169.7
Iridium	Ir	193.0	191.5	Tin	Sn	119.0	118.1
Iron	Fe	55.9	55.5	Titanium	Ti	48.1	47.7
Krypton	Kr	81.8	81.2	Tungsten	W	184.0	182.6
Lanthanum	La	138.9	137.9	Uranium	U	238.5	236.7
Lead	Pb	206.9	205.35	Vanadium	V	51.2	50.8
Lithium	Li	7.03	6.98	Xenon	X	128	127
Magnesium	Mg	24.36	24.18	Ytterbium	Yb	173.0	171.7
Manganese	Mn	55.0	54.6	Yttrium	Yt	89.0	88.3
Mercury	Hg	200.0	198.5	Zinc	Zn	65.4	64.9
Molybdenum	Mo	96.0	95.3	Zirconium	Zr	90.6	89.9

GENERAL INDEX.

INDEX TO MINERALS

Names of described species are in heavier type, varieties and synonyms in lighter type ; the first numbers refer to the descriptions.